Leonardo's Living Earth, by Stephen Jay Gould

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May 1997 Volume 106 Number 4

26 **The Crystal Fuel**
Twenty quadrillion cubic meters of the earth's methane are locked up in hydrates–a crystal lattice of water and gas that forms beneath the seabed. Although they hold more carbon than the earth's combined deposits of coal, oil, and conventional gas, these hydrates are unstable and can decompose in some spectacular ways.
Kevin Krajick Illustrations by Kirk Moldoff

32 **Trouble with Honeybees**
European settlers brought honeybees to North America for wax and honey. Once the bees' role in pollination was understood, they became agribusiness's bees of choice. Now they are in trouble. *Sue Hubbell Photographs by Gary Braasch*

42 Unsung Heroines of Pollination
If an insect on a flower is packing in the pollen, it's bound to be a bee. Here's a guide to, and an appreciation of, the less conspicuous pollinators. *Suzanne Batra*

Discovery
44 **Where Life Springs Ephemeral**
Fed by snow and rain, vernal pools fill when spring arrives, then dry up in early summer. In this short time, they harbor a key forest ecosystem. *Mark P. DesMeules and Philip Nothnagle Photographs by Gustav W. Verderber*

Cover: Yellow-spotted salamander eggs and newly hatched larvae are part of a vernal pool community in the Vermont woods. *Story on page 44. Photograph by Gustav W. Verderber*

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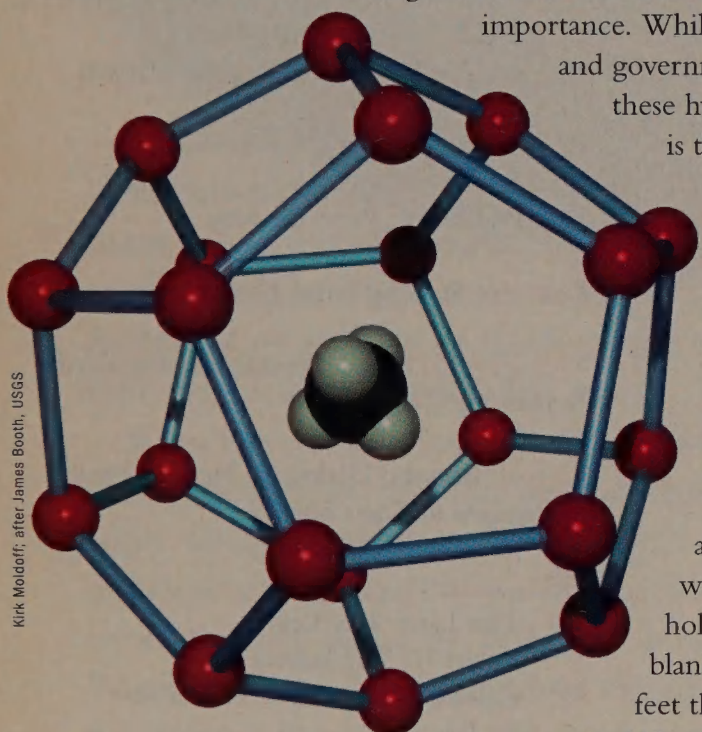
Finding the Crystal Fuel

Rocks don't usually get great press. The study of geology—if it doesn't concern earthquakes or volcanoes—can seem more like documentation than discovery, a reading of the record of change in the earth's history. Most often the discoveries in biology or genetics make the news. But geology makes news in this month's story by Kevin Krajick on the natural history of gas hydrates ("The Crystal Fuel," page 26). That this crystalline lattice of gas and water—usually formed beneath the seabed at high pressures and low temperatures—existed in any quantity is a fairly new finding. But that the amount of carbon tied up in these deposits may be twice that of all the earth's coal, oil, and gas reserves put together makes the discovery one of international importance. While exploration companies and governments want to know how these hydrates (in which methane is the predominant gas) might be exploited for energy use, geologists are just beginning to explore the role hydrates play in the earth's ecosystem. Could a rise in sea temperatures release methane—a known "greenhouse gas"—into the atmosphere and accelerate global warming? These deposits hold enough methane to blanket the earth in a layer 130 feet thick. Could their release cause shifts in the sea floor? Expeditions are now exploring the methane fields, their origins, and their natural history. Krajick, who last wrote for *Natural History* on the exploration of another geological formation, Arctic eskers ("An Esker Runs Through It," May 1996), gives us a look at the exciting scientific work in progress.



Kirk Moldoff; after James Booth, USGS

The crystalline architecture of methane hydrate

In the last year, we have had the pleasure of introducing many new contributors to *Natural History.* This month we are again pleased to feature the work of science journalists new to the magazine: Sue Hubbell ("Trouble with Honeybees," page 32) is the author of *The Book of Bees: And How to Keep Them* and *A Country Year: Living the Questions.* Natalie Angier ("Ernst Mayr at 93," page 8) is a Pulitzer Prize-winning *New York Times* science correspondent and author of *The Beauty of the Beastly.* We look forward to more articles by these writers in the coming months, along with the work of other new contributors.—*Bruce Stutz*

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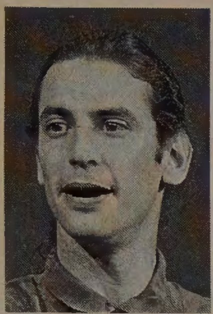

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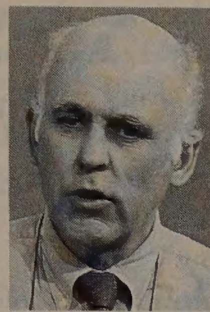

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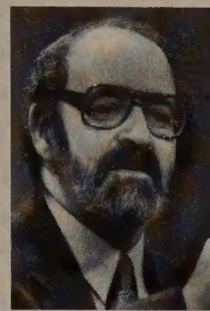

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To the Editor

When Worlds Don't Collide

In his essay in the March 1997 issue, "Nonoverlapping Magisteria," Stephen Jay Gould commented on John Paul II's recent statement that the Church has no quarrel with the teaching of evolution. Gould suggested that (except for fundamentalists) there has never been a conflict between science and theology, as they occupy separate spheres. The essay provoked an unusual amount of mail. A sampling follows:

The concept of non-overlapping magisteria is not, as Professor Gould calls it, a rapprochement, but an attempt—laudable, but futile in my opinion—to juggle two opposing worldviews.
Nice try.
David T. Benedetti
Albuquerque, New Mexico

As a Roman Catholic, I am delighted that the Church has finally, publicly, and unequivocally recognized the reality of evolutionary theory. The article would have benefited from one addition: a recognition of the churchman most influential in arguing this case. I refer to paleontologist and theologian Pierre Teilhard de Chardin (1881–1955), who incorporated evolutionary theory into his Catholic theology.
Alfred J. Piro
Brooklyn, New York

The pope recognizes scientific progress in evolutionary studies in the last fifty years. Bravo. The invitation now goes to Gould and other agnostic scientists to examine their understanding of the divine.
Larry Elmer Smith
Danville, Illinois

It was with great relief that I read the "good news" of Pope John Paul II's endorsement of evolution. I am now eagerly looking forward to the Holy Father's reflections on superstring theory, the source of the power of quasars, the confirmation of Fermat's last theorem, and perhaps the location of Elvis Presley.
Emil M. Murad
Huntington Beach, California

If the Catholic Church has fully accepted the theory of evolution, then it is faced with an interesting question: at what point in our evolution did we become human and the infusion of souls begin?
Lars-Erik Larson
Whitewater, Wisconsin

The theistic evolutionists who perceive man as descended from lower animals, and who also claim to be truly Christian, probably believe in salvation. But at what point would developing hominids become suitable to save? People who hold such mutually exclusive views are sometimes called schizophrenics.
Richard Rimmer
Madison, Tennessee

I appreciated very much Stephen Jay Gould's discussion of religion and science. When I was chaplain at Renssalaer Polytechnic Institute, in Troy, New York, many discussions with intelligent, believing students and professors of science led me to the following schema: We need science to explore the "what" and "how," and we need religion—whatever one's faith—to answer "who" and "why."

It seems we most often get into disputes when either authority insists on answering questions in the other's domain.
Rev. Harry E. Chase
Tenafly, New Jersey

I was startled as I read through Gould's latest essay. Such a rewriting of history would have won an award from the old Soviet empire. I assume the article was written to remove conflicts from those minds that are closed to depending upon themselves.
W. F. Garrott
Gainesville, Florida

The article uses some big words to hornswoggle the reader into believing that truth and falsehood can be compatible. Either there is a God, and he/she created the universe, or there is not, and he/she did not.
Eugene H. Harlow
Houston, Texas

Natural History's E-mail address is nhmag@amnh.org

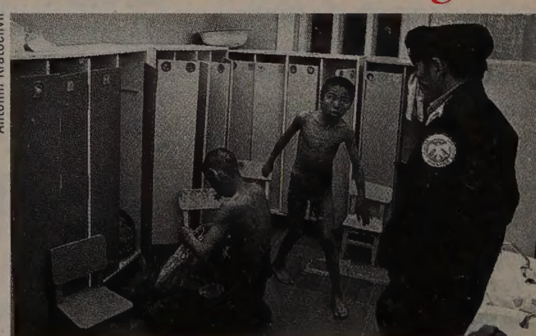
In the coming issues of

NATURAL HISTORY

Anthropology

The Streets of Mongolia

Antonin Kratochvil



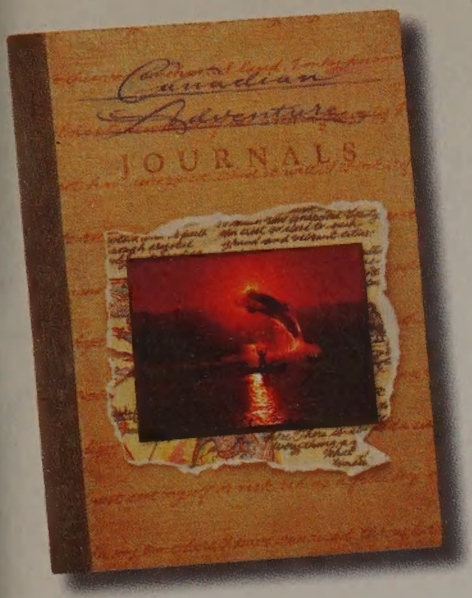
Economic changes in Mongolia have begun to strain the cultural fabric of the country. The cities are more crowded, and for the first time, homeless children wander the streets. Sherylyn Briller, an anthropologist who has lived in Mongolia, and photographer Antonin Kratochvil capture the urgency of the children's plight.

Evolution

How Did the Giraffe Get Its Neck?

A biologist wonders whether the giraffe's neck evolved for fighting, rather than for feasting on the leaves of tall trees.

NH97



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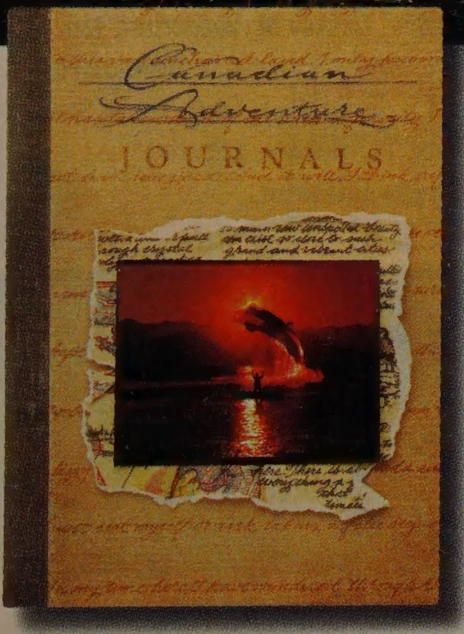

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A professor of psychology at the University of Sussex, **George Butterworth** ("Starting Point") studies the intellectual development of infants, especially the origins of language in preverbal babies. He has studied "joint attention" (how a baby knows where others are looking) for about twenty years. Research on pointing was a natural extension of this work. Recently, his daughter Francesca has provided assistance.

Frans B. M. de Waal ("Bonobo Dialogues") and **Frans Lanting** (at right in photo) hope their new book *Bonobo: The Forgotten Ape,* will increase public awareness of this intriguing primate. As they write in the preface, "books and articles on the other apes easily fill a small library; for a complete collection of literature on bonobos, a single cardboard box will do." Professor of psychology at Emory University and research professor of psychobiology at the Yerkes Regional Primate Research Center in Atlanta, de Waal is the author of several books, including *Good-Natured: The Origins of Right and Wrong in Humans and Other Animals* (1996). Lanting's photographs have appeared in many magazines; his books include *Okavango: Africa's Last Eden* (1993).

Kevin Krajick ("The Crystal Fuel") has done some of his more exciting research in the Arctic, about which he has written a number of stories. Some of his more uncomfortable research has been conducted at sea—recently on board the

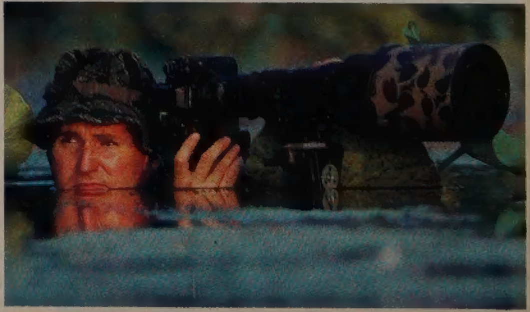
Point Lobos as it pitched and rolled off the California coast, where scientists were conducting experiments on the formation of gas hydrates. Krajick survived—to continue his concentration on science and the environment. He has written for many publications, including *Smithsonian, Audubon,* and *Discover.*

Writer **Sue Hubbell** ("Trouble with Honeybees") recently moved from her farm in Missouri, where she kept honeybees for twenty-five years, to the coast of Maine, where the environment is better for watching intertidal invertebrates than for raising bees. Hubbell has published several books on bees and other subjects; her latest is *Far Flung Hubbell: Essays from the American Road* (1995). Entomologist **Suzanne Batra**, right, works in the Bee Research Laboratory of the U.S.D.A. Agricultural Research Service, in Beltsville, Maryland. Batra ("Unsung Heroines of Pollination"), who reports that she has been interested in bees since she was three years old, has worked on everything from bee sociobiology to systematics. Her fieldwork has taken her to many countries, most often India, where she is currently working on a survey of fruit-pollinating bees of the Garhwal Himalayas. Photographer **Gary Braasch**'s pictures have been published in more than 100 magazines worldwide. He is known for action coverage of risk-taking field science, including volcano, forest canopy, and ecological studies.

Mark P. DesMeules ("Where Life Springs Ephemeral") first became interested in vernal pools when he learned to ice skate on one as a small child. DesMeules, left, is now director of Land for Maine's Future and coordinator of the state's Natural Resource and Economics Initiatives. A former director of science and stewardship for the Nature Conservancy in Vermont,

he designated Vermont's vernal pools protected wetlands. His coauthor, **Philip Nothnagle**, a forest ecologist trained at Dartmouth, is an expert on the ecology of tiger beetles. **Gustav M. Verderber**, left, whose pictures accompany their article, has an M.S. in zoology from Ohio State University. He pursues nature photography full time.

Derrick Hamrick ("The Young and the Nestless") found that his life changed on his twenty-fifth birthday, when he "started to see the world through a viewfinder." Since then, Hamrick—who is also a firefighter—has steadily taught himself the photographic craft. He spent hundreds of hours observing wood duck nesting cavities before capturing the youngster in this month's "Natural Moment." Although he has traveled widely, Hamrick finds many of his subjects near his home on the Neuse River in rural Wake County, North Carolina. He used a Nikon F4, Nikkor 500 mm f4 lens, and high-speed flash to catch the day-old duckling's leap of faith.



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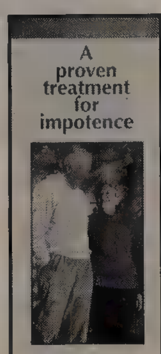

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Ernst Mayr

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Interview *Ernst Mayr, one of the world's greatest evolutionary biologists and the sort of living legend who's already in the* Encyclopaedia Britannica, *is ninety-three going on twenty-three—twenty-three books, that is. In the course of a long and surpassingly productive career, Mayr has written books on subjects as varied as evolution, ecology, ornithology, systematics, and the philosophy and history of biology, as well as publishing more than 600 scientific articles. He is a founder, along with Theodosius Dobzhansky, Julian Huxley, and George Gaylord Simpson, of the so-called modern evolutionary synthesis, the conceptual breakthrough that brought together a genetic understanding of how species*

at 93

Left: Mayr in Cambridge, Massachusetts, September 1996. Above: Mayr at this summer home in Wilton, New Hampshire, about 1955.

adapt to their environment with an ecological consideration of why there is such a spectacular degree of biodiversity in the first place. Mayr (pronounced MIRE) also helped define the most enduring concept of a species—simply put, as a group of interbreeding populations—and established a philosophy of biology to rival the philosophical tenets of any other science.

Born and educated in Germany, Mayr emigrated to the United States in 1931, working first as a curator at the American Museum of Natural History, then moving to the Museum of Comparative Zoology at Harvard, where he is a professor emeritus. As a young man, he studied the magnificent birds of paradise in New Guinea, and he has described more species and subspecies of birds than any other biologist alive. Mayr is opinionated and elitist, courtly and generous, and still working two decades after his supposed retirement. His twenty-first book, This Is Biology: The Science of the Living World, *has just been published by Harvard University Press; his twenty-second book is now being edited; and his twenty-third is in progress. Natalie Angier, a Pulitzer Prize-winning science writer for the* New York Times, *visited him at his winter home in Winter Park, Florida, near Orlando, to talk about* This Is Biology *and Mayr's views on life as it is—and as it can never be.*

How in the world did you end up here in Winter Park?

My life is nothing but a series of accidents. Coming here was an accident, too.

Did you want to be close to Disney World?

No, I've never been to Disney World. This is my fifth winter down here, and I haven't gone there. I said that to somebody and apologized for it, but he said, "Why apologize? You should be proud."

Your latest book goes over many of the themes that you've been interested in for much of your career. What is the take-home message of the new book?

The point of the book is that the great public, and that includes even most biologists, don't have the correct image of the science of biology. Many still have the idea that the physical sciences, physics, and the mathematical sciences are real science and everything else is inferior science. The physicist Ernest Rutherford once referred to the other sciences as postage-stamp collecting. Now, physics is perfectly good science, but it's a special science, and many things about it don't apply to the other sciences. By the same token, many things about the other sciences don't apply to physics. Yet they're all perfectly good science. Furthermore, I point out that at the present time, biology is the leading science. It has more to do with the problems we face, our contact with the environment, our future as a species, than does any other science. I come out very strongly in saying that understanding the principles of biology is what's most important for the future.

It seems that there's a real interest in Darwin now, almost a Darwin mania. People are writing about him, applying his ideas to human behavior, and so forth.

Owing to the power of physicalist and essentialist thinking, Darwin was neglected and misunderstood for seventy-five years after 1859. Indeed, it was widely believed that Darwin was no philosopher. Actually, most of the principles of biology were more or less proclaimed by him in 1859. Before him, you had a truly anthropocentric world. It was expressed in the Bible, where God says to Adam, this is your world, you can do with it what you please. Darwin, of course, showed otherwise, that we're descended from the apes. And as recent molecular research indicates, we're incredibly close to the apes, to the chimpanzees. But that doesn't mean man is "nothing but an animal." Two characteristics are unique to humans. One is language, grammar, and syntax, and all that. All our attempts to teach apes language have been totally unsuccessful. A chimpanzee cannot express something like, "Tomorrow I would like an apple for lunch." Another characteristic that we alone have, and Darwin stated this clearly, is an ethical system.

Has there been anything equivalent to Darwin's work in this century?

I don't know of anything. Freud's the-

ory of the unconscious was a great achievement, but it wasn't comparable to Darwin's.

What do you make of the fact that people continue to resist the idea of evolution? About 40 percent of Americans do not believe in it.

At least that amount. It has something to do with the poor quality of education in America. Many students here don't even know where Mexico is located.

You talk at length in your book about proximate versus ultimate causes, and the importance of addressing both in trying to understand how life works.

Yes, this is part of the philosophy of biology, that there are two causations in biology, proximate and ultimate. The proximate causation is the one that answers the "how" questions. Physiology, molecular biology, and developmental biology all study proximate causations of how something works. But then we have the ultimate causations, which ask the "why" questions. Evolutionary biology, much of ecology, and behavioral biology are all concerned with the why questions. Why do birds migrate to warm climates in the winter? They've been selected to do so because otherwise they would die in the winter.

Do you think the proximate fields like molecular biology are in ascendance these days? You've quoted biochemist George Wald, who said, "All biology is molecular."

George Wald's claim was based on strict reductionism, and reductionism is dead. It's now so clear that every time you have a more complex system, new qualities appear that you could not have predicted from the components. That's the principle of emergence. I once gave a lecture in Copenhagen, and I said something I now realize to be wrong. I said, emergence is characteristic only of biology. That was in 1953, when emergence was very suspect, nobody believed it. The famous physicist Niels Bohr got up to object, and I thought he'd say emergence was metaphysical and supernatural and all sorts of things. Instead he said, "We have emergence all over the inanimate world," and he gave the famous example of water. If you know all the characteristics of hydrogen and all the characteristics of oxygen, you still couldn't predict that the product would be liquid. So that's the end of reductionism.

As for molecular biology, there's no branch of biology that doesn't use molecular techniques now, because they're so extraordinarily powerful. But since we have the problem of emergence, it's clear that molecular biology alone isn't the whole answer.

The concept of group selection was once taboo, but now it's undergoing a kind of resurrection. What do you think of it?

In my book, I focus on two kinds of group selection, which I call soft and hard group selection. If a group is superior because all of its individuals are superior, and it's still individual selection, then I call it soft group selection. However, if the social group as an entity has more success in the struggle for existence because there's internal cooperation—they jointly search for food, they have sentinels warning of enemies—then we have hard group selection, which goes beyond the average fitness value of the components.

In other words, the whole is greater than the sum of its parts.

Exactly. Hard group selection is very important for human evolution, because our ancestors consisted exactly of these cooperating social groups. And as anthropologists have known forever and ever, some of these groups were more successful than others at driving away competitors from a water hole, or just wiping them out. Genocide is a part of our history. On the other hand, I think it was exactly the selection of social groups that furthered the development of the ethical system, including altruism. Here I disagree with those sociobiologists who don't believe in group selection.

How much do you think we can understand about our nature by taking the perspective of sociobiology, or evolutionary psychology as it's called nowadays? The relationship between men and women, for example?

Most of the behaviors between males and females have nothing to do with sociality. They're behaviors between two individuals, each acting with the ultimate objective to enhance individual reproductive success. This is true even of things like sibling rivalry. Most of these interactions are not social phenomena in the broad sense, and that's why I don't like to call it sociobiology. But when you come to the real social phenomena, the migrations of wildebeests or whales, you won't read a word about them in the sociobiological literature.

At the present time, biology has more to do with the problems we face, and our future as a species, than does any other science.

Where do you think the human species is going? Do you believe we can continue to evolve in a genetic sense?

There's absolutely no chance of the human species evolving. First of all, we can never speciate. We cover every niche, every spot on the earth, so there's no opportunity for isolation. Moreover, I do not feel there's any natural selection in any positive sense going on right now. Of course, there are those who have talked about eugenics, but we all know that eugenics is impossible for many reasons. I can't see the development of man into superman or anything like that. Theoretically, we could have cultural evolution and develop higher and better concepts. But if you have no basis for a change in

genes, then unfortunately you can only develop through cultural evolution.

Why do you say "unfortunately?"

Because the cultural things can be lost so quickly.

On the subject of ethics and eugenics, your own background is interesting. You left Germany in 1931, at the start of the Nazi era.

I had a very interesting life, no question about it. I came from the fourth generation in which there was a medical doctor, and I was to be a medical doctor. But I switched to zoology because I was very adventurous and wanted to see the world. I wanted to go on an expedition. Fortunately, just as I was finishing my doctorate, Lord Rothschild needed somebody in New Guinea.

Did you like being in New Guinea?

Well, it's exciting, but it's a tough life, I'll tell you that. I had malaria, I had dysentery, I had dengue, I had everything you can have. Weeks would go by and there was no one to talk to except natives, and I was always alone.

I understand you were living off the land and eating birds of paradise, among other things. What does a bird of paradise taste like?

Most land birds really taste almost about the same. They have a soft and rather flavorful meat. I ate only one bird that was absolutely awful, and that was a cormorant. That was so fishy it was almost inedible.

Do you keep a regular schedule for work?

More or less. I have an alarm that wakes me up at 6:15 every morning. I have a little kitchenette. I take one meal outside, and one I make myself. I'm quite active. I write, give lectures, travel abroad.

Have you had any major disappointments, any regrets?

Well, I probably do, but I'm one of these euphoric guys. I always look to the future and never look back. □

How Does Biology Explain the Living World?

"I wanted to write a 'life history' of biology that would introduce the reader to the importance and richness of biology as a whole," writes Mayr in his new book.

Excerpted from This is Biology: The Science of the Living World, *by Ernst Mayr, Harvard University Press. Copyright 1997, by Ernst Mayr. All rights reserved. Reprinted by permission.*

AMNH

1932, New Guinea: Mayr (right) with his Malay guide, after two months in the interior.

Excerpt When biologists try to answer a question about a unique occurrence, such as "Why are there no hummingbirds in the Old World?" or "Where did the species *Homo sapiens* originate?" they cannot rely on universal laws. Biologists have to study all the known facts relating to the particular problem, infer all sorts of consequences from the reconstructed constellations of factors, and then attempt to construct a scenario to explain the observed facts of this particular case. In other words, they construct a historical narrative.

Because this approach is so fundamentally different from causal-law explanations, the classical philosophers of science—coming from logic, mathematics, or the physical sciences—considered it inadmissible. However, recent authors have vigorously refuted the narrowness of the classical view and have shown not only that the historical-narrative approach is valid but also that it is perhaps the only scientifically and philosophically valid approach in the explanation of unique occurrences.

Of course, proving categorically that a historical narrative is "true" is never possible. The more complex a system is with which a given science works, the more interactions there are within the system—and these interactions very often cannot be determined by observation but can only be inferred. The nature of such inference is likely to depend on the background and the previous experience of the interpreter; therefore, not surprisingly, controversies over the "best" explanation frequently occur. Yet every narrative is open to falsification and can be tested again and again.

For instance, the demise of the dinosaurs was once attributed to the occurrence of a devastating disease to which they were particularly vulnerable, or to a drastic change of climate caused by geological events. Neither assumption was supported by credible evidence, however, and both ran into other difficulties. Yet in 1980 when the asteroid theory was proposed by Walter Alvarez—and, particularly, after the presumed impact crater was discovered in Yucatán—all previous theories were abandoned, since the new facts fit the scenario so well.

Among the sciences in which historical narratives play an important role are cosmogony (the study of the origin of the universe), geology, paleontology, phylogeny, biogeography, and other parts of evolutionary biology. All these fields are characterized by unique phenomena. Every living species is unique and so is, genetically speaking, every individual. But uniqueness is not limited to the world of life. Each of the nine planets of the solar system is unique. On earth, every river system and every mountain range has unique characteristics.

Unique phenomena have long frustrated the philosopher. David Hume noted that "science cannot say anything scientifically about the cause of any genuinely singular phenomenon." He was correct if he had in mind that unique events cannot be fully explained by causal laws. However, if we enlarge the methodology of science to include historical narratives, we can often explain unique events rather satisfactorily, and sometimes even make testable predictions.

The reason historical narratives have explanatory value is that earlier events usually make a causal contribution to later events. For instance, the extinction of the dinosaurs at the end of the Cretaceous vacated a large number of ecological niches and thus set the stage for the spectacular radiation of the mammals during the Paleocene and Eocene. The most important objective of a historical narrative is to discover causal factors that contributed to later events in a historical sequence. □

The Compleat Darwin

The Darwin Multimedia CD-ROM *(second edition, edited by Pete Goldie). Lightbinders, Inc. (800) 432-3766. Available in Macintosh and Windows.*

By Richard Milner

CD-ROM All the Darwinian mainstays are here—the *Origin of Species* (1859), *Descent of Man* (1871), *Expression of the Emotions in Man and Animals* (1872), and the books on coral reefs and orchid pollination. But, until now, only a few lucky bibliophiles could also own the scarce *Zoology of the Beagle,* with its treatises on fossil and exotic animals collected during Darwin's famous voyage—and now complemented by Toshio Asaeda's 1932 watercolors of Galápagos fishes. Here, too, is Darwin's rarely seen 1,200-page monograph on barnacles, a classic of systematics on which he worked for eight years. There is also a chronology of events in Darwin's life, a biographical dictionary of Victorian naturalists, a bibliography of 1,500 primary and secondary sources on the Darwinian legacy, and Sir David Attenborough's fund-raising video tour of Darwin's home, Down House. A sampling of Darwin's short papers ranges from a theory of mountain building to questions on the perceptions of ants. (Were the insects more "terrified" by the smell left by a human finger in their path or by "the sight of their dead and dying comrades"?) A special feature allows the user to select any word or phrase in Darwin's writings and instantly find out where and how many times it appears.

Celebese macaques, from Darwin's Expression of the Emotions in Man and Animals, *1873.*

In the 1840s, a small committee that included young Darwin established new guidelines for naming animal species. This reformation of the taxonomic rules, for which the CD-ROM provides the complete text, became internationally accepted, establishing Linnaeus's double-naming system (genus and species) as the standard in science. (In its text, the committee complains that an English scientist working in France finds "their *scientific* language almost as foreign . . . as their vernacular.")

Michael Ghiselin's *Triumph of the Darwinian Method* is also reprinted here, with a new introduction by the author. First published twenty-five years ago, Ghiselin's landmark book helped convince the scholarly world of Darwin's enduring achievements at a time when facile detractors had tarnished his reputation. Ghiselin reiterates his ultimately triumphant view that Darwin was "a first-rate thinker and theoretician, and one of the most successful polymaths of all time."

My frustration in communicating the richness of this compilation is perhaps best expressed in Darwin's own words, taken from a letter reproduced on the CD-ROM. After summarizing his theory for a friend, he apologized: "This sketch is most imperfect; but in so short a space I cannot make it better. Your imagination must fill up very wide blanks."

Richard Milner, an editor at Natural History, *is the author of* Charles Darwin: Evolution of a Naturalist *(1994) and* The Encyclopedia of Evolution *(1993).*

On-Line Evolution

By Robert Anderson

nature.net

Surprisingly, Charles Darwin has a rather low profile in cyberspace, but his ideas, which will undoubtedly stir debate until the end of time, have spawned lots of sites on the Internet—many created by creationists. Nevertheless, there are a few good places to look for insight into Darwin's thinking and the modern synthesis that builds on his theory of natural selection. The Evolution Homepage http://bioinfo.med.utoronto.ca/~lamoran/Evolution_info.shtml is a good place to start. It has links to most of the related sites, including the electronic versions of Darwin's most important works.

An excellent discussion of how Darwin's ideas differed from his predecessors'—and how they fit into modern thinking—can be found in a chapter in Gary Cziko's book *Without Miracles* http://www.ed uiucedu/facstaff/g-cziko/without_miracles/02.html.

A nascent Web magazine called *The Evolutionist* http://www.lse.ac.uk/depts/cpnss/evolutionist/ was created to give wider exposure to some newer ideas that attempt to explain human behavior by putting it into an evolutionary context. But if evolutionary psychology, as this is called, is not your cup of tea, try my favorite evolution site—The Virtual Flylab, at California State University at Los Angeles http://vflylab.calstatela.edu/edesktop/VirtApps/VflyLab/IntroVflyLab.html. Here, you can design your own fruit flies, mate them to create new offspring, and learn the rules of genetic inheritance in the process. I like to think that Darwin, who never knew about the genetic underpinnings of natural selection, would have enjoyed this one, too.

Robert Anderson is a freelance writer living in Los Angeles.

Bookshelf

Darwin's Orchestra

By Michael Sims (Henry Holt and Company, 1997, $30, illus.)

Arranged in an almanac format, this is a treasure trove of odd, entertaining, quirky—and significant—episodes from the annals of natural history, highlighting the interplay between science and popular culture.

Eyewitness to Discovery

Edited by Brian M. Fagan (Oxford University Press, 1997, $39.95, illus.)

This collection of more than fifty first-person accounts of some of the world's greatest archeological discoveries includes Hiram Bingham's of Machu Picchu in 1911, Howard Carter's of Tutankhamen's tomb in 1922, and Brian Fagan's of China's Han Dynasty tombs in 1977.

Virtual Archaeology

Edited by Maurizio Forte and Alberto Siliotti (Harry N. Abrams, Inc., 1997, $49.50, illus.)

High-definition, three-dimensional computer images, aerial photographs, maps, diagrams, and text by experts are used to reconstruct ancient places known only from archeological sites.

Peter Schouten

Tree Kangaroos

By Tim Flannery, Roger Martin, and Alexandra Szalay; illustrated by Peter Schouten (Reed Books, Australia, 1996, $100, illus.)

This authoritative book on the natural history, evolution, and conservation status of the world's seventeen species and subspecies of tree kangaroos is splendidly illustrated by artist Schouten's full-page watercolor portraits.

The Heat Is On

Ross Gelbspan (Addison-Wesley, 1997, $23)

A Pulitzer Prize-winning journalist argues that conservative politicians and energy industrialists are trying to dismiss the significance of recent cataclysmic weather and other evidence that the earth is warming. Gelbspan analyzes work by scientists on both sides of the issue and suggests ways to protect the environment as the global climate changes.

Another America

By Mark Warhus (St. Martin's Press, 1997, $29.95, illus.)

A 1708 map, depicting Towasa Indian Lamhatty's account of his enslavement and revealing a vigorous colonial trade in Indian slaves, is one of the more than seventy-five documents that chronicle Native American perspectives on the relentless and often brutal European advance across the North American continent.

The books mentioned in "Natural Selections" are available by mail order from the Museum Shop of the American Museum of Natural History, (212) 769-5150.

By George Butterworth

All photographs by Pamela Duffy

Tugging on her mother's jacket, a small child, too young to talk, points her index finger at a puppy in a pet shop window. A geography teacher points to various countries on a map as he calls out their names. An angry father points at a dent in his new car and asks his teen-age son, "How did that happen?"

Pointing with the index finger, arm extended in the direction of the interesting object, remaining fingers curled under the hand, thumb held down and to the side, is a vital part of human communication. Sometimes, it is accompanied by speech; often not. We point at things we know and at things we have never seen before. Pointing can be a way of telling—making a point—or asking. Always, however, the intention is to draw someone else's attention to an object or event of interest.

Drawing attention to an object or an interesting event is part of communication for a number of species. A hunting dog signals that it has found prey by standing still and "pointing" with its whole body (from nose to tail) and bent

In the beginning was the Word . . . and an outstretched index finger.

Starting Point

foreleg. Vervet monkeys have several predator-specific alarm calls to warn troop members when danger is near. But unlike finger pointing, most such behavior is restricted to specific situations. Will the dog, for example, point to indicate to its owner the whereabouts of a bone that has gotten wedged under the couch? And just how intentional is the signal? Would the dog point at prey or the vervet give an alarm call even if it had no audience?

Finger pointing is apparently unique to humans. Of course, most animals don't have fingers to point with, but even our fellow apes don't point in their natural state. After extensive interactions with humans, apes sometimes use an extended hand to refer to things, but they practically never extend the index finger separately when making the gesture. In a recent study done at Emory University, David Leavens, William Hopkins, and Kim Bard found that a chimpanzee named Clint sometimes uses a form of index finger pointing to draw his trainer's attention to food that has fallen out of reach. Clint, however, has never pointed for the benefit of other chimps, and even with his trainer, he uses his flat hand more often than his index finger. Is there anything special about finger pointing in humans?

Charles Darwin proposed the principle of antithesis to explain how animals convey information. The aggressive posture of a dog preparing to fight, for example, involves many of the same muscles it uses when it adopts the subdued posture of submission.

The postural antithesis of finger pointing is the pincer grip, in which the tip of the index finger and thumb are in opposition. This contrast in the relative position of thumb and index finger is correlated with a change in the focus of attention. In manual tasks involving the pincer grip—holding a pencil, removing a thumbtack, tying shoelaces—the focus is on the object and the job at hand. Pointing, in contrast, directs the attention of another person toward an object some distance off.

Human babies begin to point at about eleven months. (Before they point or understand pointing, they turn their heads in response to other signals—head and eye movements, for example, or shifts in body orientation—that indicate a change in a parent's focus of interest.) In the 1920s, Russian psychologist Lev Semeonovitch Vygotsky suggested that babies may learn pointing from their mothers and that the gesture begins as a way to request objects that are out of reach. Fabia Franco, of the University of Padua, and I tested this hypothesis. We observed how babies who had just begun to point behaved when placed in a room with attractive toys just out of reach and with dolls some way off. We found that the babies (seated in highchairs next to their mothers) both reached for and pointed at the nearby toys, whereas the distant dolls elicited only pointing. Infants looked at their mothers, both while pointing and immediately afterward, to check whether they had succeeded in redirecting their attention.

Apparently unique to humans, finger pointing is closely correlated with language acquisition. The earlier babies start to point, the more words they know by twenty months of age.

In another study, Franco, Paula Perruchini (a student from the University of Rome), and I found that a baby will also point to redirect the attention of another baby, even though neither can yet speak. This time, mothers were seated behind their babies, out of their sight. Our results convinced us that pointing originates as a declaration of interest and a wish to share the experience of an object, not as a consequence of failing to get ahold of it.

Nobuo Masataka, of the Primate Research Center of Kyoto University, found that while interacting with their mothers, three-month-old human babies extend their index fingers rhythmically and make speechlike cooing sounds at the same time. This gesture, a precursor of pointing, together with the results of other experiments Franco and I conducted, suggests that babies are not taught to point by adults. Mothers validate the gesture through their own reactions, but they do not create it.

A number of studies show that finger pointing is related to both gesture and speech. Paul Morissette, of the University of Montreal, and I found that the age at which a baby first points is a good predictor of its progress in understanding language—as measured by the number of indicative gestures (such as pointing with a flat hand or closed fist, clapping, or waving) in the baby's repertoire five months later and how many animal noises the baby recognizes. Margaret Harris, of the University of London, has shown that babies first point in the same week they begin to understand names for objects, such as cat and ball.

Pointing does not necessarily precede a baby's first word. In one of our studies,

Morissette and I found that the average age of pointing was 327 days for girls and 350 days for boys. At approximately the same ages, girls already had a vocabulary of three to four words; boys, one. The rate of speech acquisition, however, is correlated with the onset of pointing. Luigi Camioni, of the University of Rome, has found that the earlier babies begin to point, the more words they know at twenty months of age.

Lida Graupner (a postdoctoral fellow working in my laboratory) and I recently established that as long as an object is in the middle of their field of view, most babies are more likely to point with their right hand than their left. (For objects on the periphery, they point with the hand on the same side of the target.) This preference for the right hand may reflect the relative contributions of the left and right parietal areas of the brain (known to be active when adults pay attention to objects in their right or left visual field) and may suggest connections in the nervous system between areas of the brain that control pointing and those involved in speech perception and production. In right-handed people, the major speech centers are located in the left hemisphere, which is the same side of the brain that controls the right hand.

Graupner, Franco, and I also found that when we added sound to the dolls, so that they spoke to the baby as they moved (saying "Hello, baby" and making squeaky sounds like those of a Walt Disney cartoon character), fifteen-month-old baby girls were more likely than boys of the same age to point with the right hand. Such coordination between seeing, hearing, and right-handed pointing may help them learn that sounds refer to things and may explain the often reported advantage many girls enjoy in acquiring speech.

The frequency and speed with which babies point depend on the complexity of the event they have observed. At La-Trobe University in Australia, Beryl McKenzie and I showed babies a toy clown designed to do three things, separately or in combination: rotate on its axis, travel slowly across the babies' field of vision, and "vanish" behind a screen. The more complicated the combination of movements, the longer it took a baby to point. When we combined all three movements, babies generally didn't start pointing for a full ten seconds after the clown disappeared. After this, however, the babies began pointing, vocalizing excitedly (often imitating the squeaky sounds of the clown), and checking with their mothers. It was as though the babies were pointing into the past, as if to say, "Wow, did you see that?"

Once babies start to point with the index finger, they much prefer this to other indicative gestures in their repertoire, such as extending a flat hand or closed fist. Pointing turns out to be more than a means of reorienting someone else's attention; it is a crucial step on the road to language. □

A little girl points with the index finger of her right hand to draw another baby's attention to something interesting in front of her. A preference for right-handed pointing is common, additional evidence that pointing and speech are connected. In right-handed people, the left hemisphere of the brain controls the right hand and houses the major speech centers.

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Seeking to explain sea fossils on mountain ridges, Leonardo developed his theory of the living earth

By Stephen Jay Gould

Morgan describes his despair as their captors string up King Arthur for a hanging: "They were blindfolding him! I was paralysed; I couldn't move, I was choking, my tongue was petrified. . . . They led him under the rope." But, in the best cliffhanging tradition, and at the last conceivable instant, Sir Lancelot comes to the rescue with 500 knights—all riding bicycles.

> ***Lord, how the plumes streamed, how the [redacted] flamed and flashed from the endless procession of webby wheels! I waved my right [redacted] as Lancelot swept in. . . . I tore away noose and bandage, and shouted: "On your knees, every rascal of you, and salute the king! Who fails shall sup in hell tonight!"***

I am not citing either Monty Python or *Saturday Night Live,* and I didn't mix up my genders in the first sentence. The speaker is not Morgan le Fay (who, no doubt, would have devised a magical, rather than a technological, solution to the same predicament) but Hank Morgan, the Connecticut Yankee in King Arthur's court in Mark Twain's satirical novel of the same name. Morgan, transported from nineteenth-century Hartford, wreaks mayhem in sixth-century Camelot by introducing all manner of "modern" conveniences, including tobacco, telephones, baseball—and bicycles.

As a literary or artistic device, anachronism exerts a powerful hold upon us and has been a staple of all genres from the highest philosophy to the lowest comedy—as Jesus is crucified in a corporate boardroom by Dali, condemned at his second coming by Dostoyevsky's Grand Inquisitor, but only offered a half-price discount (as he changes to modern dress) by the Italian barber or the Jewish tailor of various ethnic jokes, now deemed tasteless and untellable.

Anachronism works this eerie and potent effect, I suppose, because we use the known temporal sequence of our history as a primary device for imposing order upon a confusing world. And when "the time is out of joint; O cursed spite," we really do get discombobulated. We also know that correction of a perceived time warp cannot be achieved so easily in real life as in magical fiction (where Merlin can put Hank Morgan to sleep for 1,300 years, or Dracula can be dispatched with a wooden stake driven into the right spot). We regard Hamlet's blithe confidence as a mark of his madness when he completes his rhyming couplet with the Shakespearean equivalent of "no sweat" or "hakuna matata"—"That ever I was born to set it right!"

Science, for reasons partly mythical, but also partly accurate and defendable, presents itself as the most linear and chronologically well ordered of all disciplines. If science, working by fruitful and largely unchanging methods of reason, observation, and experimentation, develops progressively more accurate accounts of the natural world, then history provides a time line defined by ever expanding success. In such a simple, linear ordering, mediated by a single principle of advancing knowledge, any pronounced anachronism must strike us as especially peculiar—and subject to diametrically opposite judgment depending upon the direction of warp. An ancient view maintained in the present strikes us as risible

and absurd—the creationist who wants to compress the history of life into the few thousand years of a literal biblical chronology, or the few serious members of the flat earth society. But a "modern" truth, espoused out of time by a scholar in the distant past, fills us with awe and may even seem close to miraculous.

A person consistently ahead of his time—a real-life Hank Morgan who could present a six-shooter to Julius Caesar or explain the theory of natural selection to Thomas Aquinas—can only evoke a metaphorical comparison with a spaceman from a more advanced universe or a genuine angel from the realms of glory. In the entire history of science, no man seems so well qualified for such a designation as Leonardo da Vinci, who died in 1519 but filled his private notebooks with the principles of aeronautics, the mental invention of flying machines and submarines, and a correct explanation for the nature of fossils that professional science would not develop until the end of the eighteenth century. Did he have a private line across the centuries to Einstein, or even to God himself?

I must confess that I share, with so many others, a lifelong fascination for this man. I was not a particularly intellectual child; I played stickball every afternoon and read little beyond comic books and school assignments. But Leonardo captured my imagination. I asked, at age ten or so, for a book about his life and work, probably the only intellectual gift that I ever overtly requested from my parents. As an undergraduate geology major, I bought the two-volume Dover paperback edition of Leonardo's notebooks (a reprint of the 1883 compilation by Jean-Paul Richter) because I had read some of his observations on fossils in the *Codex Leicester* and had been stunned not only by their accuracy but also by their clear statement of paleoecological principles not clearly codified before our century and still serving as a basis for modern studies.

What goes around, comes around—as Leonardo must have said somewhere. This *Codex Leicester*—one of Leonardo's most important notebooks, filled largely with commentary on the nature and use of water—first came to light in the 1690s, when Giuseppe Ghezzi found the document in a chest of manuscripts in Rome. In 1717, Thomas Coke, later Lord Leicester (hence the codex's name), purchased the notebook, which remained in his family until Armand Hammer bought it in 1980—and renamed it, in Trumpian fashion, *Codex Hammer.* With enormous fanfare (at enormous profit), Christie's auctioned this notebook on November 11, 1994, when America's Bill Gates outbid several European governments and bought the manuscript for more money than I can count. Gates, to his credit, restored the original name and has favored public exhibition of the document—including a show at the American Museum of Natural History in 1996, where I finally saw this icon of my dreams and admiration, and where I developed the ideas for this essay. This is the only manuscript of Leonardo's now residing in America.

Leonardo remains, in many ways, a frustrating and shadowy figure. He painted only about a dozen authenticated works, but these include two of the most famous icons in our culture, the *Mona Lisa* (in the Louvre) and the *Last Supper* (a crumbling fresco in Milan). He published nothing in his lifetime, despite numerous and exuberant plans, although several thousand fascinating pages of manuscript have survived, probably representing only about a quarter of his total output. He did not hide his light under a bushel and was, in life, probably the most celebrated intellectual in Europe. Dukes and kings reveled in his conversation and his plans for war machines and irrigation projects. He served under the generous patronage of Europe's most powerful rulers, including Ludovico il Moro of Milan, the infamous Cesare Borgia of Florence, and King Francis I of France.

Leonardo's notebooks did not become generally known until the late eighteenth century and were not published (and then only in fragmentary and occasional form) until the nineteenth century. Thus, he occupies the unique and peculiar role of a "private spaceman"—a thinker of preeminent originality, but whose unknown works had no influence at all upon the developing history of science (for nearly all his great insights had been rediscovered independently before his notebooks came to light).*

The overwhelmingly prevailing weight of public commentary about Leonardo

*An air of impenetrability continues to surround Leonardo. A scholar must still struggle to obtain a complete translation of any document like the *Codex Leicester.* The Richter edition of Leonardo's notebooks is maddeningly fragmentary, and the individual passages of the codices are broken apart and rearranged by subject. (Thus, you can find Leonardo's statements about water under a common heading, as abstracted from all his notebooks, but you cannot put together the text of the *Codex Leicester*—admittedly a hodgepodge and miscellany, but scholars do need to trace sequential jottings, however motley the apparent medley, for Leonardo often made odd juxtapositions for interesting reasons.) The other major edition of Leonardo's notebooks—Edward MacCurdy's compilation of 1939, and my source of quotation for this essay—is far more adequate (and nearly complete for the *Codex Leicester*), although also broken up by topic.

I must confess to a wry amusement (which might have blossomed to near fury if I had a different temperament) at the recent exhibit of the codex. Visitors could see all the original pages and buy a beautiful catalog with each page reproduced in full facsimile. But no printed translation could be found anywhere, and the catalog only provided a pitifully scrappy summary of each page. You could purchase a CD-ROM with the full text (as Bill Gates showed his true commitment!), but most homes don't have a machine for playback, and the version that I tried to use couldn't even put a full line, with Leonardo's marginal annotations, on the screen at once. Moreover, a scholar can't work with only one part of a text on a screen at a time. You have to be able to compare passages from several pages at once—as you can do with an old-fashioned book. I almost felt as though our modern age of the passive sound bite—the attitude of "we know what little bit you need"—had launched a conspiracy against scholarship to keep Leonardo hidden. I do love to consult original sources in their original languages but my skills (and patience) do not extend to long bouts of reading medieval Italian in a mirror!

continues to view him as Western culture's primary example of a "spaceman," that is, as a genius so transcendent that he could reach, in his own fifteenth century, conclusions that the rest of science, plodding forward in its linear march to truth, would not ascertain for several hundred years. Leonardo stood alone and above, we are told over and over again, because he combined his unparalleled genius with a thoroughly modern methodology based on close observation and clever experiment. He could therefore overcome the ignorance and lingering, sterile Scholasticism of his own times.

For example, the "Introductory Note" in the official catalog for the recent exhibition of the *Codex Leicester* summarizes the basis of Leonardo's success in these words: "In it [the codex] we can begin to see how he combined almost superhuman powers of observation with an understanding of the importance of experimentation. The results were inspired insights into the workings of nature that match his artistic achievements." When such conventional sources acknowledge the persisting medieval character of many Leonardian pronouncements, they almost always view this context as a pure impediment to be overcome by observation and experiment, not as a matrix that might have been useful to Leonardo, or that might help us understand his beliefs and conclusions. For example, the closing passage of the long *Encyclopaedia Britannica* article on Leonardo states: "Leonardo approached this vast realm of nature to probe its secrets. . . . The knowledge thus won was still bound up with medieval Scholastic conceptions, but the results of his research were among the first great achievements of the thinking of the new age because they were based on the principle of experience."

Frankly, and to say so quite baldly, I think that this conventional view could not be more wrong in its general approach to the history of knowledge—or more stultifying for our quest to understand this most fascinating man of our intellectual past. Leonardo did make wonderful observations. He did often anticipate conclusions that public science would not reach for another two or three centuries. But he was neither spaceman nor angel—and we will never understand him if we insist on reading him as Hank Morgan, a man truly out of time, a modernist among the Medici, a futurist in the court of Francis I.

Leonardo operated in the context of his time. He used his basically medieval and Renaissance concept of the universe to pose the great questions and to organize the subjects and phenomena that would generate his phenomenal originality. If we do not chronicle—and respect—the medieval sources and character of Leonardo's thought, we will never understand him or truly appreciate his transforming ideas. All great science, indeed all fruitful thinking, must occur in a social and intellectual context—and contexts can promote insight as well and as often as they constrain thought. History does not unfold along a line of progress, and the past was not just a bad old time to be superseded and rejected for its inevitable antiquity.

In this essay, I will try to illustrate the centrality of Leonardo's largely medieval context by analyzing his remarkable paleontological observations in the *Codex Leicester.* I will begin by acknowledging their truly prescient character, but will then raise two questions that expose the early-sixteenth-century context of Leonardo's inquiry: "What alternative account of fossils was Leonardo trying to disprove by making his observations?" and, "What theory of the earth was Leonardo trying to support with his findings?" Leonardo did not make his observations to win the praises of future generations; he studied fossils to probe these two questions of his own time—and his answers could not be more deeply embedded in a "modernity" of his own century, which we would now mock and dismiss as hopelessly antiquated. Thus, we cannot understand Leonardo's paleontology when we only marvel at his empirical accuracy and ignore the reasons for his inquiry.

Yes indeed, a thousand times yes, the observations are often stunningly accurate—as experts have always said, and for the reasons always stated. Moreover, their degree of detail, and their centrality to the basic rules of modern paleoecological analysis, only enhance the impression that they must be coming from a Victorian geologist somehow trapped in the early sixteenth century. But let me stop marveling and start listing a small sample:

1. Leonardo recognized the temporal and historical nature of horizontal strata by correlating the same layers across the two sides of river valleys:

> *How the rivers have all sawn through and divided the members of the great Alps one from another; and this is revealed by the arrangement of the stratified rocks, in which from the summit of the mountain down to the river one sees the strata on the one side of the river corresponding with those on the other.*

(All quotes, unless otherwise stated, come from the *Codex Leicester* as presented in the MacCurdy version of Leonardo's notebooks.)

2. He observed that rivers deposit large, angular rocks near their sources in high mountains, and that transported blocks are progressively worn down in size and rounded in shape, until sluggish rivers deposit gravel, and eventually fine clay, near their mouths. (I learned this rule as principle number one on day number one in my college course in beginning geology):

> *When a river flows out from among mountains it deposits a great quantity of large stones. . . . And these stones still retain some part of their angles and sides; and as it proceeds on its course it carries with it the lesser stones with angles more worn away, and so the large stones become smaller; and farther on it deposits first coarse and then fine gravel . . . until at last the sand becomes so fine as to seem almost*

like water . . . and this is the white earth that is used for making jugs.

3. The presence of fossils in several superposed layers proves their deposition at different and sequential times.

4. The tracks and trails of marine organisms are often preserved on bedding planes of strata: "How between the various layers of the stone are still to be found the tracks of the worms which crawled about upon them when it was not yet dry."

5. If both valves of a clam remain together in a fossil deposit, the animal must have been buried where it lived, for any extensive transport by currents after death must disarticulate the valves, which are not cemented together in life but only hinged by an organic ligament that quickly decays after death. (This principle of inferring transport by noting whether fossil clams retain both valves remains the primary rule of thumb for everyday paleoecological analysis. I doubt that any pre-nineteenth-century geologist mentioned this observation in more than a casual manner, while Leonardo regarded the argument as central. This is the observation that first inspired my undergraduate awe for Leonardo, for I had just learned the rule in class and had thought: "How clever; how modern.")

> *And we find the oysters together in very large families, among which some may be seen with their shells still joined together, which serves to indicate that they were left there by the sea and that they were still living.*

At another site, on the other hand, Leonardo inferred extensive transport after death:

> *In such a locality there was a sea beach, where the shells were all cast up broken and divided and never in pairs as they are found in the sea when alive, with two valves which form a covering the one to the other.*

6. Leonardo often illustrates the so-called uniformitarian principle of using observations on current processes to infer past events. To get some idea of potential spatial distribution in a layer of fossils, he notes, in a striking example, how far a cockle can move in a day:

> *It does not swim, but makes a furrow in the sand, and supporting itself by means of the sides of this furrow will travel between three and four* braccia *in a day. [A* braccio, *or "arm," measured about two feet.]*

7. No marine fossils are ever present in regions or sediments not once covered by the sea.

8. When fossil shells are found broken in pieces and heaped one upon the other, we may infer transport by waves and currents before deposition:

> *But how could one find, in the shell of a large snail, fragments and bits of many other sorts of shells of different kinds unless they have been thrown into it by the waves of the sea as it lay dead upon the shore like the other light things which the sea casts up upon the land?*

9. The age of a fossil shell can often be determined by growth rings that may record astronomical cycles of months or years. (Sclerochronology, or the analysis of growth periodicities, has become a rigorous and important subject in paleobiology only during the current generation.) We can, Leonardo writes, "count on the shells of cockles and snails the numbers of months and years of their lives just as one can on the horns of bulls."

I have often, in these essays, quoted a favorite line from Darwin: "How can anyone not see that all observation must be for or against some view if it is to be of any service." Leonardo's keen observations do seem to emit a wondrous whiff of modernity, but when we learn why he made his inquiries and note how he ordered his facts, we can begin to place him into the proper context of his own world. Leonardo did not observe fossils for pure unbridled curiosity, with no aim in mind and no questions to test. He recorded all his information explicitly to confute the two major interpretations of fossils current in his day. Both had been proposed to resolve a problem that had deeply troubled Western natural history ever since antiquity: If fossil shells are the remains of marine organisms (and some are virtually indistinguishable from modern species), how did they get entombed in strata that now lie within mountains, several thousand feet above current sea level?

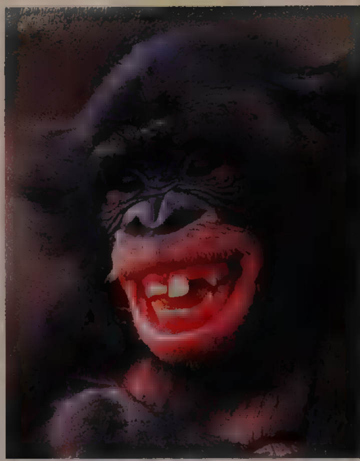
First, Leonardo disproves and ridicules the common idea that all fossils were transported to mountains by the high waters and violent currents of Noah's flood. Observations 3 to 6 of my list all serve this purpose by showing that many fossils are preserved in their position of life, undisturbed by any movement after death. One flood cannot produce a fossil record in several sequential layers (observation 3). Strata formed by violent currents could not preserve the feeding tracks of worms (observation 4). Noah's floodwaters would have disarticulated all fossil clams into separate valves (observation 5). As for the cockle, laboriously moving but six to eight feet a day in its furrow, forty days and nights of rain would scarcely provide enough time for a journey 250 miles inland (where fossil cockles now reside) from the nearest modern sea:

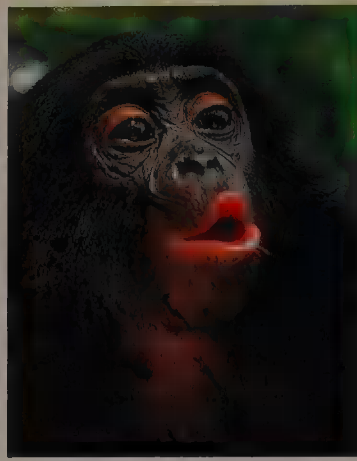
> *With such a rate of motion it would not have travelled from the Adriatic Sea as far as Monferrato in Lombardy, a distance of 250 miles, in forty days—as he has said who kept a record of this time.*

Moreover, Leonardo adds, cockle shells are too heavy to be transported at the tops of waves, and they cannot be swept up the mountains along the bottom of the waters because, Leonardo believed, the bottom currents always move down from higher to lower elevations, even while waves and surface currents sweep inland. The explicit refutation of Noah's flood as a cause of fossils forms a major theme of the

(please turn to page 58)

Story by Frans de Waal
Photographs by Frans Lanting





Bonobo Dialogues

For decades, scenarios of human evolution have depicted our ancestors as "killer apes," progressing from aggression to hunting and warfare. While work on some monkeys and apes (notably baboons and chimpanzees) supported this view, studies of the most recently recognized ape species, the bonobo, both in the wild and in captivity, certainly do not.

The bonobo (sometimes known as the pygmy chimpanzee) was officially distinguished from its sibling species, the chimpanzee, in 1929. Until then, bonobos were often mistaken for young chimpanzees because of their juvenile appearance. The bonobo remained little more than a curiosity, however, until the 1970s, when Japanese and Western scientists traveled to Zaire to begin documenting the natural history of this elusive anthropoid. These scientists have revealed the

A male invites a female for sex by displaying an erection and a stick of sugarcane.

An adult male bonobo grooms an adult female. Studies of captive bonobos indicate that males seek contact with females, while females prefer the companionship of their own sex.

one-sidedness of previous attempts to reconstruct the behavior of the common ancestor of humans and apes.

Bonobo society, unlike that of chimpanzees, is best characterized as female centered and egalitarian, with sex substituting for aggression. Females occupy prominent, often ruling positions in society, and the high points of bonobo intellectual life are found not in cooperative hunting or strategies to achieve dominance but in conflict resolution and sensitivity to others.

My own work with bonobos began in 1983, when I set out to study a colony of

Bonobos, far left and center, have flatter, more open faces, wider nostrils, and smaller ears than does a chimpanzee, left. The facial expressions of the two kinds of ape are remarkably similar, however; nervous grins and pouts are typical of both.

ten individuals at the San Diego Zoo. My intention was to develop the first detailed "ethogram," a systematic catalog of the species' facial expressions, gestures, and vocalizations. To get the necessary information, I stood in front of the bonobos' enclosure for hundreds of hours, observing and videotaping them.

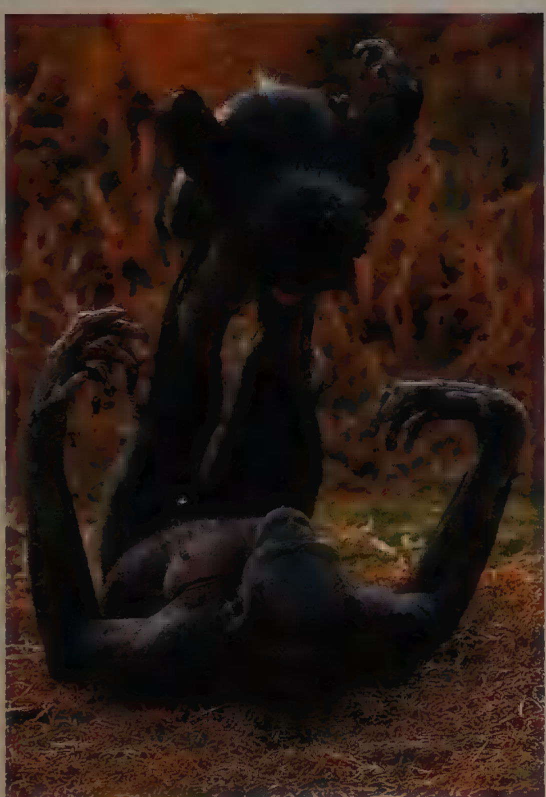
One day, I watched as two adult males were reintroduced after a long separation. They both screamed and circled each other for six minutes without making any physical contact. The ape keepers and I feared a bloody confrontation (most animals fight when introduced to a relative stranger of the same sex), but Kevin, the younger male, kept stretching out his hand and flexing his fingers, as if beckoning Vernon to come closer. Occasionally, Kevin shook his hands impatiently.

Both males had erections, which they presented to each other with legs apart, in the same way that a male bonobo invites a female for sex. It was as if each male wanted contact but did not know whether the other could be trusted. When they finally did rush toward each other, instead of fighting, they embraced frontally with broad grins on their faces, Vernon thrusting his genitals against Kevin's. They calmed down right away and happily began collecting the raisins that the caretakers had scattered around. Instead of screaming, they now uttered excited food calls.

The way this brief but tense encounter unfolded—the intense exchange of signals, the genital contact, and the peaceful ending—is emblematic of the species. Aggressive behavior is not absent in the bonobo, either in captivity or in the wild, but it remains mostly mild and restrained compared with the elaborate charging displays for which the chimpanzee is so well known.

A male chimpanzee appears larger than life when he raises his hair, uproots a small tree, and charges about slapping the ground with great force and energy. When he is in this mood, anyone who crosses his path risks a beating. He can keep up the performance for minutes; perhaps the length and vigor of the display informs his fellows about his health and stamina. In the Mahale Mountains National Park, in Tanzania, Japanese primatologist Toshisada Nishida observed a high-ranking male chimpanzee that had developed a habit of displaying near a riverbed with enormous rocks, which he would dislodge and roll downhill, producing a thunderous noise that seemed to impress his rivals.

In comparison, the bonobo male's typical display looks like harmless play. He will grab a branch and drag it behind him while making a brief run. The unstoppable steam-engine display enacted by his more robust relative could not be more different. Also, bonobos rarely perform the complex confrontations known among chimpanzees, in which one animal recruits supporters against another, thus forcing the opponent to do the same, until entire sections of society oppose each other on the battlefield. Chim-



Ape mothers play games that promote eye contact with their offspring.

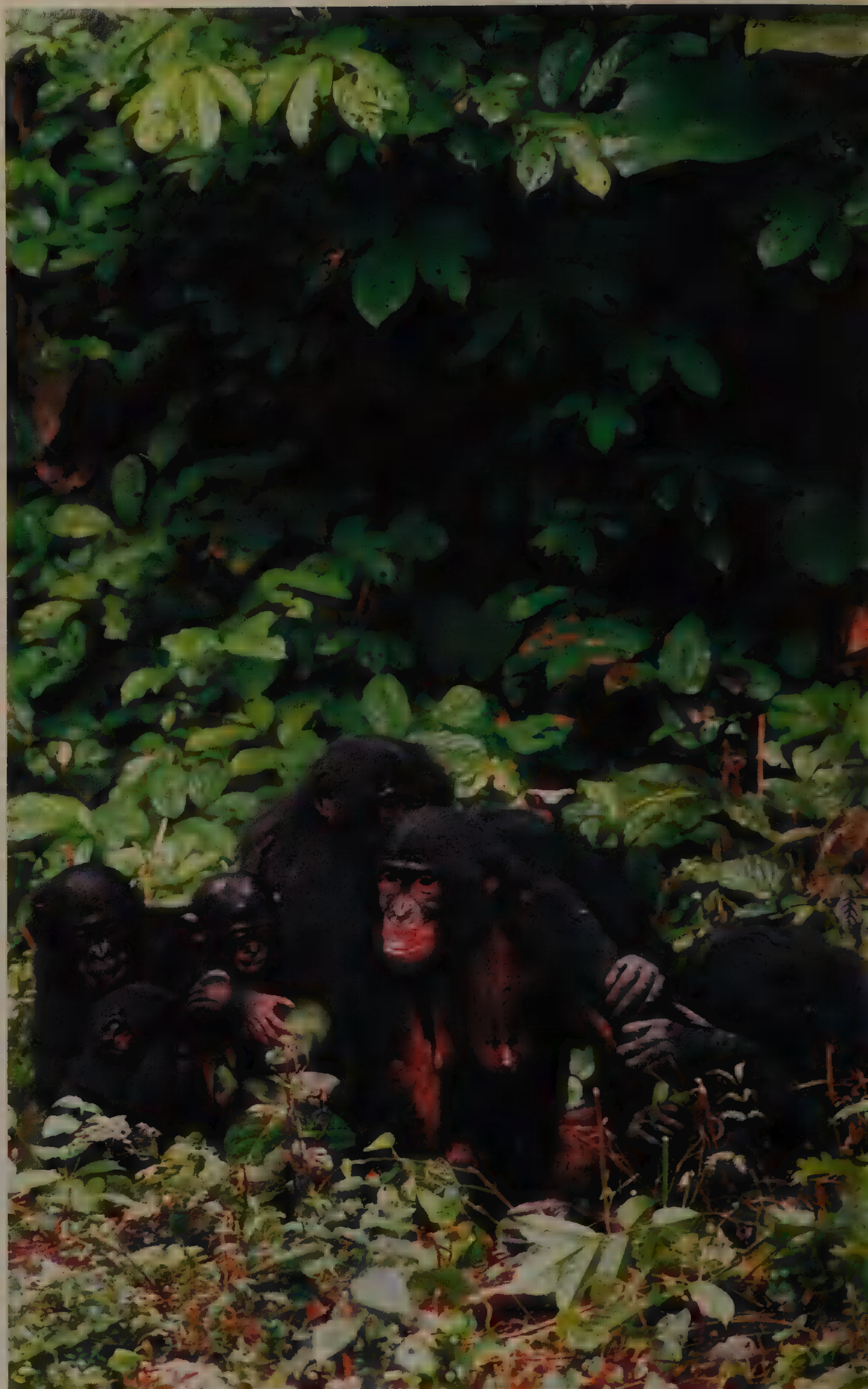
Bonobo females often rub genitals, usually to relieve tension in relationships.

panzees will go around cajoling their friends to get involved, holding out a hand to one, embracing another. As a result, confrontations may last half an hour or more, involving all sorts of shifting alliances and lots of screaming and barking. Bonobos, in contrast, fight chiefly on a one-on-one basis without maneuvering to draw in third parties.

This is not to say that a bonobo placed together with chimpanzees would be at a loss about what is going on among them, or that bonobos themselves never form alliances. They are capable of the same kinds of interactions, yet they rarely engage in confrontations on the grand scale characteristic of the chimpanzees' political system.

Chimpanzees go through elaborate rituals in which one individual communicates its status to the other. When two adult males meet, one will grovel in the dust, uttering panting grunts, while the other stands on two feet and performs a mild intimidation display to make clear

Bonobos have long, graceful limbs and, compared with chimpanzees, small heads.



In the rain forests of Zaire, bonobo mothers nurse their young for four years and take them with them everywhere they go.

who ranks above whom. Overall, communication patterns related to aggression, dominance, and submission are more conspicuous and spectacular in the chimpanzee. This species seems to invest considerably more energy, both physical and mental, in politicking: the chimpanzee is the Machiavelli of the primate world.

Are we permitted to speak of "politics" in relation to animals other than ourselves? If we follow the social scientist Harold Lasswell's classic definition of politics as "who gets what, when, and how," then why shouldn't the dominance strategies and alliances of nonhuman primates

be labeled as such? In baboons and chimpanzees, for example, two males may band together to defeat a third; such alliances determine sexual access to females, and thus decide who gets what.

As soon as such alliances come into play, a higher level of social awareness is required. It becomes of paramount importance to know not just who your friends and enemies are but also who the regular allies of your adversaries are, so that their presence or absence can be taken into account. Success demands keeping track of a large number of social factors, hence the thesis, forwarded by primatologists in the 1960s, that social problem-solving is the original function of primate higher mental functions (including those of humans).

Bonobos often walk on two legs when they have food in their hands. This captive female is carrying ginger leaves.

If chimpanzees indeed engage in the most elaborate power strategies, they might represent the best example of socially driven brain evolution. Does this mean that the bonobo, being less political, is less intelligent? Indications are that bonobos resolve the question of who gets what, when, and how by different, somewhat subtler means. In bonobo society, the accent seems to have shifted toward peaceful settlement of conflicts of interest.

This brings me to the domain in which bonobos excel. If, of the twin concepts of sex and power, the chimpanzee has an appetite for the second, the bonobo clearly has one for the first. The chimpanzee resolves sexual issues with power; the bonobo resolves power issues with sex. In sexual matters, chimpanzees follow an almost laughably simplistic scheme. Bonobos have more ways of inviting each other sexually, more ways of engaging in sex, and a greater variety of facial expressions and vocalizations associated with sexual intercourse than do chimpanzees. The chimpanzee's sex life is rather plain and boring; bonobos act as if they have read the *Kama Sutra*.

By far the most striking contrast between the two, however, is in vocal communication. The voices of the two species are so different that it is easy to tell them apart. Not only is the bonobo's voice shriller but its calls are often quite distinct. For example, the long-distance call of the chimpanzee is a slowly swelling hoot, whereas the bonobo utters nervous, agitated whooping calls. Heard from a distance, these calls sound like the yapping of a small dog, or rather many small dogs, because bonobos synchronize such calls to a high degree, producing choruses in which individuals "echo" one another.

An even more remarkable coordination is achieved during aggressive confrontations. Each opponent may vocalize in alternation with the other, exchanging sounds as fast as the back-and-forth of a professional Ping-Pong match. They seem to be trading information about emotions and intentions. The calls are variable: some may be threats, others may betray fear, and yet others may express a desire to reconcile.

During the reunion between Kevin and Vernon, the two males went through this kind of rapid dialogue in a very intense manner. A spectrographic analysis of their calls indicated that they changed in quality over the course of the encounter but remained similar to each other's (a process known as vocal matching), as if the two males gradually converged on a solution to their predicament. Their calls almost never overlapped—that is, the two males responded to each other without interrupting. Ten years before my study, Claudia Jordan, a German ethologist, had already reported so-called squeal duels when one bonobo confronts another. Possibly what chimpanzees do by means of visual displays of strength and determination, bonobos do by a more "languagelike" exchange of information about their internal states. It would be going too far to claim that they are talking the issue over, but there is a certain dialectic and coordinated quality to the bonobos' vocal contests that is absent in the chimpanzee.

The bonobo's natural communication, as well as many other fascinating aspects of its behavior, has not yet received the attention it deserves. These little-known primates are endangered in the wild and extremely rare in captivity. If we take good care of them, however, we may for a long time share this planet with a family member that affords us an entirely new look at ourselves.

Excerpted from Bonobo: The Forgotten Ape, *by Frans de Waal, photographs by Frans Lanting. Printed by permission of the University of California Press, 1997.*

The Crystal Fuel

Laura Stern/John Pinkston; USGS

By Kevin Krajick

In 1976 scientists on an international drilling expedition off the coast of Guatemala brought up a core of gritty mud from the deep-sea floor. In it were several softball-size nodes of a whitish, icelike material no one on board had ever seen before. The nodes popped, hissed, and snapped like frying bacon, sputtering out gas and throwing off droplets of liquid. Within minutes the only thing left was a puddle of water. "We measured and photographed it every which way," says Bill Harrison, a geologist at the Idaho National Environmental Engineering Laboratory, who was on board. "We knew what we had."

What they had were bits of gas hydrates—chemical compounds that are increasingly being studied for their potential as huge reservoirs of energy, as possible causes of sea floor instability, and even as significant contributors to global warming. Scientists had long speculated about them and even made them in the laboratory, but until now only a few had been seen in nature.

Explorations under the sea floor reve

Hydrates are a peculiar combination of two common substances: water and natural gas, usually methane. If these meet in sediments where pressure is high and temperature low—a combination produced under oceans and the permanently frozen subsoil (permafrost) of polar regions—they join together in an extraordinarily compact form found nowhere else. But retrieving a chunk is extremely difficult. Unlike diamonds or oil, hydrates quickly decompose into their two components when they are pulled up from the depths toward warmth and low pressure—thus the rush of gas and water that the scientists saw on deck. They were lucky to witness even that; decomposition usually happens long before hydrates hit the surface.

Since the 1970s, scattered studies have spotted about fifty areas where significant deposits may exist, says Keith Kvenvolden, a U.S. Geological Survey scientist in Menlo Park, California. There is a rough consensus that 20 quadrillion cubic meters of methane are locked up in hydrates—enough to blanket the earth's surface with gas 130 feet thick. Measured another way, hydrates may hold 10 trillion tons of carbon, twice as much as the earth's coal, oil, and conventional gas reserves combined. The estimate is based on just a few dozen recovered hydrate samples, as well as on seismic profiles of the sea floor, chemical analyses of drill cores, and extrapolations about where conditions exist for hydrate formation. "There's still a lot of speculation,"

notes Kvenvolden. "God knows what the reality is."

Studies show that most of the gas for hydrates is made when anaerobic bacteria break down organic matter under the sea floor, producing methane and an array of gaseous byproducts, including carbon dioxide, hydrogen sulfide, and small amounts of ethane and propane, all of which can be incorporated into hydrates; methane, however, predominates. Various thermal reactions can also produce methane for gas hydrates. As gases rise, they are dissolved in whatever water is in the sediment. At the right pressure-temperature combination—the "stability zone"—hydrates will form. In theory, most ocean bottoms provide stability zones, but in practice, hydrates seem confined to the edges of continents, where nutrient-rich waters send a rain of organic detritus into the muds for bacteria to turn into methane and where the water is at least 1,000 feet deep. Although gas hydrates can be found at the sea floor, their usual range is 325 to 3,600 feet beneath it. In permafrost, they can occur at shallower depths because of colder temperatures.

The basic hydrate unit is a hollow crystal of dozens of water molecules; inside, a single gas molecule floats freely. The crystals fit together in an extremely tight latticework. To the naked eye, hydrates (also known as clathrates, from the Greek and Latin words for "cagework") look like ice. But hydrate crystals are cubic rather than hexagonal, and hydrates usually form above the freezing point of water. Also, unlike ice, hydrates can be set on fire because they are amazingly efficient packages for flammable methane. The crystal structure effectively contains the compressed gas; in a cubic foot of hydrates, gas will expand in volume to about 164 cubic feet at standard temperature and pressure.

Depending on local conditions, hydrates may be found in nodules, veins, solid layers, or finely dispersed particles between sediment pores. But they usually can't be seen. Only in a few places—the Gulf of Mexico is one—do visible lobes crop out on the sea floor. Hydrates have also been found under sediment off the Oregon coast, in 10,000-foot-deep water. In 1995 geologists drilling along the peat-rich Arctic coast of Canada's Northwest Territories discovered hydrates for the first time in permafrost itself, 400 feet down. Russian and Japanese scientists have found hydrates deep in the Antarctic ice sheet, formed from ancient bubbles of atmospheric nitrogen and other gases.

Since hydrates are nearly impossible to observe directly, researchers have relied on a surrogate: making them in the laboratory. This involves shaking, heating, cooling, or otherwise manipulating gas and water or ice particles for hours or days—a process that probably little resembles what actually happens in nature.

How exactly do they form? How long does it take? If you find a chunk, is it a few hours old or 20,000 years old? These are some of the questions that are being asked by Peter Brewer, a researcher at the Monterey Bay Aquarium Research Institute, who recently designed an unusual experiment: sending a remotely operated vehicle (ROV) to the bottom of an underwater chasm the size of the Grand Canyon, off Moss Landing, California. Given the natural pressure and temperature, Brewer hoped to make hydrates using methane and seawater. Accompanied by other curious scientists, he set out on a series of expeditions on the research vessel *Point Lobos.*

One of these expeditions took place over two days last October. An ROV strapped to the deck was outfitted with several clear plastic cylinders and attached by tubes to a tank of methane gas that would be released at the right moment. Video cameras were fixed to the ROV so that Brewer could see what was happening. About eight miles offshore, the ninety-seven-foot *Point Lobos* rolled heavily in ten-foot seas. Deckhands un-

Hydrates are nearly impossible to observe directly in nature, so some researchers make them in the laboratory. Opposite page: Hydrates on fire in the lab. A few researchers have also attempted to make hydrates in the sea. In October 1996, scientists monitored such an experiment in the control room of the Point Lobos research vessel, above. They sent a remotely operated vehicle, above left, into deep water off the California coast to facilitate the making of hydrates.

…vast deposits of crystallized gas hydrates—potentially our greatest source of energy.

Eduardo Citrinblum

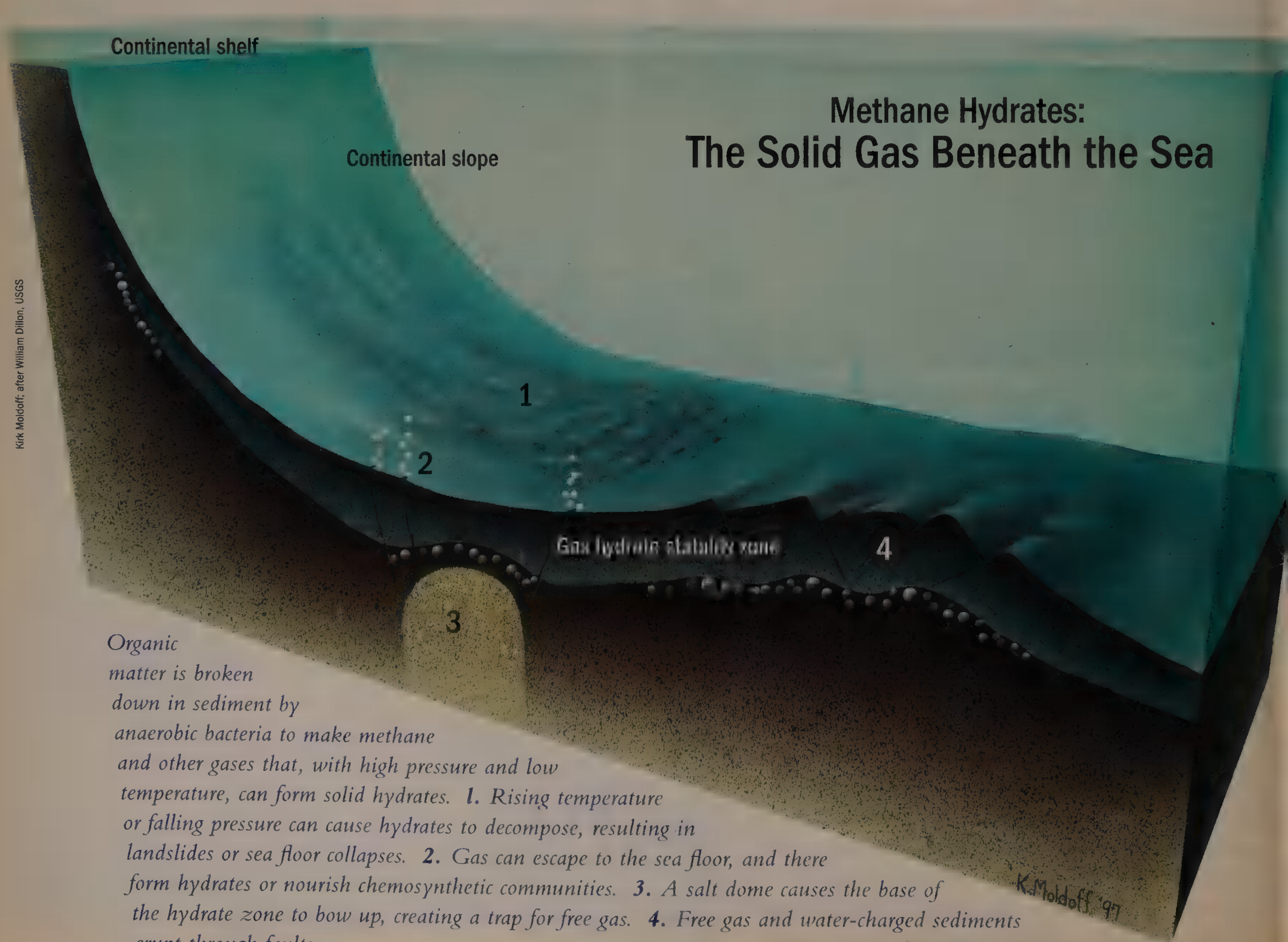
Eduardo Citrinblum

cinched the ROV, then dashed out of the way as a crane swung it over the side into the water, where it bobbed, then dived in a burst of foam. From a dark control room below deck, pilot Paul Tucker guided the ROV with a joystick. After twenty minutes, the video screen showed a swirl of brownish silt as the craft reached the bottom, 3,000 feet down. Instruments revealed that the temperature there was a brisk 3.9 degrees Celsius and the pressure 90 times that on the surface. Exotic small fishes and bright orange shrimps drifted by, but Brewer had eyes only for the cylinders. Tucker ran some seawater into them. Various instruments were checked. Finally Brewer called, "OK, give it some methane." Tucker pushed a button, and a column of bubbles rose into the water in the cylinders.

For a couple of seconds, nothing happened. Then the bubbles coalesced and turned into a cluster of spheres resembling fine, translucent pearls. Observers forgot how seasick they were, and a cheer went up. With the addition of more methane, the mass grew to the size of a rolling pin. "Look at that!" shouted Brewer. "Look how fast it forms! That's amazing!" Within minutes it had compacted itself into a snow-cone shape. But there was no way to hang on to it. When Tucker started guiding the ROV toward the surface, Brewer's snow cone began to disappear. At 1,800 feet, gas started to bubble from it, and it began to look slushy and gray. At 1,050 feet, it boiled furiously and holes appeared in it. At 850 feet, just a few fragments floated in the water. Then it was gone.

A few months earlier, a group at Texas A&M University had made hydrates with similar speed and ease by corralling natural methane that bubbled out of the ocean floor, trapping it in a tube. In November and December 1995, the Ocean Drilling Program (ODP), a worldwide consortium of scientific institutions, also

Hydrates, which contain 3,000 times more methane than the air does, cou



Kirk Moldoff; after William Dillon, USGS

Organic matter is broken down in sediment by anaerobic bacteria to make methane and other gases that, with high pressure and low temperature, can form solid hydrates. ***1.*** *Rising temperature or falling pressure can cause hydrates to decompose, resulting in landslides or sea floor collapses.* ***2.*** *Gas can escape to the sea floor, and there form hydrates or nourish chemosynthetic communities.* ***3.*** *A salt dome causes the base of the hydrate zone to bow up, creating a trap for free gas.* ***4.*** *Free gas and water-charged sediments erupt through faults.*

attempted to understand the dynamics of hydrate deposits, with intriguing results. The ODP's vessel *JOIDES Resolution* went to the Blake Ridge off the South Carolina coast and drilled into what scientists thought might be a rich hydrate field. As a 30-foot-long, 2.3-inch-wide drill core was being hauled out of the water, the free gas and/or hydrate inside the core suddenly expanded and shot out a load of hard, greenish clay, which landed two decks below. The crew managed to pick some intact hydrate pieces out of similar cores and rush them into pressurized, cooled canisters before they could decompose.

Bill Winters, a U.S. Geological Survey (USGS) civil engineer based in Woods Hole, Massachusetts, was awarded guardianship of several of those rare chunks, including one of the biggest ever—a 6.3-by-2.3-inch piece nicknamed "the Football." When the ship docked in Miami, Winters had a flatbed truck with generator-powered refrigerators waiting for the three-day drive home. On the final leg of the journey, he says, "The roads were washboards. We padded the canisters in foam and did 80 to even out the bumps." On the New Jersey Turnpike, they hit a pothole, and a seal on the Football's container failed. When Winters opened it, he found a puddle of water.

Other scientists on the cruise had used a different technique. They sent specialized canisters down into the drill hole itself to collect samples of hydrates. The canisters were sealed before being hauled up, allowing for the retrieval of completely intact samples. Later, researchers working with University of North Carolina marine geologist Charles Paull released gas from the canisters and measured it under controlled laboratory conditions—the first such direct analysis ever done. Based partly on this measurement, they estimated that the Blake Ridge alone holds enough gas to supply heat and electricity, at current usage rates, to the United States for 100 years.

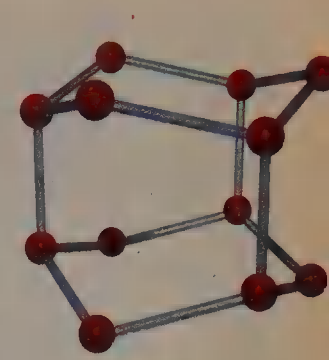
Perhaps the expedition's biggest surprise was that at least half the estimated gas was not in the hydrate layer but underneath it. Scientists had predicted that they would find a few yards worth of free methane beneath the hydrate layer. Instead, they found hundreds. "We never hit bottom, so we don't know how far down it goes," says Paull, the expedition's co-chief. How this relates to the hydrate above, no one is sure. One possibility, says Paull, is that without anything solid to get in the way, gas just escapes through loose sediment and bubbles up into the water. But when a hydrate layer starts to form, it seals the gas in, preventing it from escaping. A "mature" hydrate mass could fill the whole stability zone, at which point free gas would start building up underneath.

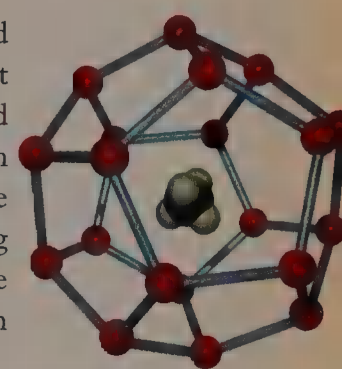
Thus, a solid hydrate mass might find itself sitting on an unstable foundation of toothpastelike, bubbly muck that was exerting upward pressure. Changes in pressure or temperature, earthquakes, or other disturbances might cause the mass to decompose, crack, or slip downhill off its fragile foundation, resulting in massive gas releases or in undersea slumps. These possibilities are of more than academic interest. The Ocean Drilling Program long forbade the *JOIDES Resolution* from drilling through hydrates, fearing that drilling could suddenly cause gases to vent and sink the ship—the rumored fate of a Russian drilling barge in the Arctic some years ago. (The Blake Ridge exploration was sanctioned, partly because the water is deep enough to mitigate such releases.) The late Richard McIver, who was a petroleum geology consultant based in Texas, even suggested that naturally disturbed hydrates could explain mysterious disappearances in the Bermuda Triangle, conveniently located in the Blake Ridge region. He speculated that water frothing with gaseous methane could sink ships or even deprive low-flying aircraft of oxygen as they passed through the concentrated gas, causing their engines to fail.

Some scientists theorize that hydrates could accelerate global warming, for they harbor 3,000 times more methane—a powerful "greenhouse" gas—than the air does at present. The atmosphere already receives some methane from bacteria operating in rice fields and wetlands, as well as from termites and ruminant livestock like cows, which harbor bacteria in their guts. National Oceanic and Atmospheric Administration experts believe that slowly decomposing gas hydrates are currently of only minor significance in natural emissions—accounting for no more than 3 percent. But what if even a few big deposits suddenly fell apart?

There is evidence that this has happened in the past. The northern Alaska coast is carpeted with signs of old underwater landslides exactly matching calculated hydrate zones. Huge scars mark the sea floor near the Blake Ridge, where landslides have also occurred. Some seem to have formed 18,000 years ago, toward the end of the last glacial age. Charles Paull says that glaciers, at their highest point, locked up enough water to lower the seas by about 400 feet from their current

ontribute to global warming if the methane were released into the atmosphere.





Gas hydrates were first discovered in 1811, but their molecular architecture has been determined only relatively recently. To the naked eye they look like ice, but they are far different structurally. Top: The atoms that form water molecules in ice are interlocked in a hexagonal system. Above: Hydrate crystals are cubic. But their basic building blocks are water molecules linked pentagonally, forming a cage large enough to trap a molecule of free-floating gas, such as methane.

Crystal diagrams by Kirk Moldoff; after James Booth, USGS

Thriving on Methane

Some hydrate deposits are actual ecosystems. They host not only methanogens—the bacteria that make the methane—and other microbes but also worms and mussels that sometimes live on top of deposits, all feeding directly or indirectly on slowly released gases. The anaerobic methanogens are members of the kingdom Archaea (meaning "ancient"), a collection of bacteria that thrive under extreme conditions. How far down these organisms live is unknown; they could define the bottom of the biosphere. Drillers have found microbes nearly two miles down in solid earth, and probably have not reached the limit.

According to Robert Carney, an ocean ecologist at Louisiana State University, hydrate deposits "are like oases" on the desertlike ocean floor; they "collect all the meager little inputs of methane and store them up and then act as a time-release capsule would." In 1995 geologist Ronald John Parkes, of Britain's University of Bristol, studied gas hydrates in 10,000-foot-deep water off the coast of Oregon. He was startled to find ten times more bacteria 650 feet beneath the sea floor than he had found on the sea floor itself. Do some of the huge numbers of microbes there break down trapped methane for food and others recycle them back into the deposit? Or both? "It's circular and confusing and complex," says Parkes. "We have to wonder whether bacteria play a role in feeding the deposits as well as the reverse."

Methane-eating bacteria may also produce large amounts of hydrogen sulfide, poisonous to most creatures, but which here rises through faults in the hydrate to the ocean floor and is consumed by different bacteria. These include *Beggiatoa,* whose strands collect in doormat-size spreads on sediment and are visible to the naked eye. Carbon dioxide, another byproduct of methane breakdown, may also bubble up, precipitating out as it hits open water to build wasp's-nest-like carbonate chimneys that continue to vent assorted gases through their hollow centers. All this buildup may help feed the hydrate deposit by impeding the emergence of gas into the water, giving it time to solidify into lobes that poke directly out of the mud.

Charles Fisher, a Pennsylvania State University biologist, has been studying such places—called cold seeps—since the 1980s. These host spectacular ecosystems. In the center of one in the Gulf of Mexico, a constant stream of bubbles emerges from the sea floor. Surrounding this is a semicircular bed of giant mussels—a new species that, Fisher and colleagues have shown, thrives on methane. Since no animal has evolved a way to utilize CH_4 molecules directly, bacteria living on the mussels' gill filaments do it for them. Around the mussel bed, hundreds of red-tipped tube worms six to eight feet long are anchored to the carbonate rocks—the only solid place on the muddy bottom. The worms take hydrogen sulfide out of the water and pass it on to symbiotic bacteria in their central sacs. If not enough gas bubbles up, they send rootlike extensions of their tubes deep into the rock and sediment to seek it out.

No one knows the extent of the cold seep's food web. Snails can be seen crawling on the mussel shells, perhaps grazing on gas-eating microbes. Predatory starfish crack open mussels. Squat lobsters try to snip off pieces of worms. Fishes cruise by.

Not all cold-seep communities overlie hydrates—gas may bubble up directly from the depths without them—but Fisher believes that some of the most productive ones do. One day he arrived at a seep to find that some worms and mussels he'd studied for several years had fallen into a new four-foot chasm in the mud. He could see a glowing mass of solid hydrate inside; a chunk had decomposed, blowing away part of the creatures' home. Despite this occasional unhappy ending, cold seeps are relatively stable places. Growth-rate studies show that mussels and tube worms can live a long time—more than 100 years in the case of the worms. In some mussel beds, thick layers of predecessors' shells and remains suggest the communities have lasted hundreds, perhaps thousands of years—ancestral villages rich with clues to past marine environments, climate, and geology.—*K. K.*

Jonathan Blair; NGS Image Collection

Mussels live on methane at a cold seep in the Gulf of Mexico.

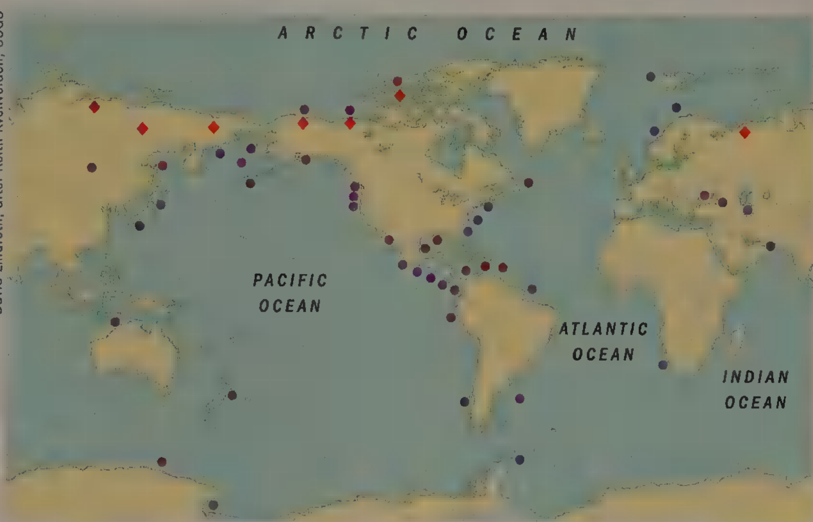
levels. This would have decreased pressures at the sea bottom and caused built-up hydrates to decompose—perhaps triggering the unexplained temperature spikes that follow most cool periods.

However, changes in temperature, not pressure, might also release hydrate masses in sufficient quantities to change climate. Ian MacDonald, an oceanographer at Texas A&M University, is examining whether local temperature changes in Gulf of Mexico currents cause gas hydrates to quickly form and decompose on the ocean floor. German researchers have studied plumes of methane gas rising from the water off the northern coast of Norway—the result, they believe, of seasonal temperature variations that warm currents and cause gas hydrates to decompose. They warn that further warming may create unpredictable currents that could set off a widening gyre of such decompositions by sending more methane into the atmosphere. James Kennett, an oceanographer at the Marine Science Institute of the University of California at Santa Barbara, is completing a study of sediments off the coast of California; it suggests that in the last 70,000 years, warm local waters have repeatedly caused large hydrate decompositions, which are associated with global warmings.

Of course, what exploration companies and governments want to know about hydrates is whether they can be exploited for energy. U.S. companies have considered pumping hot water or chemicals into deposits to destabilize them, but no one has actually tried. Conventional gas deposits from Appalachia to Texas are still plentiful and easier to get at than hydrates buried under sea floors or permafrost. Japan, however, imports 95 percent of its natural gas and pays three times more for it than the United States does. In 1995 the Japanese government and a consortium of ten companies launched a five-year plan of exploration and extraction. Preliminary surveys indicate substantial hydrate deposits off Japan's coasts. Hydrates may become "one of the most important domestic energy resources left around Japan in [the] twenty-first century," Yoshihisa Okuda, of the Geological Survey of Japan, told an international hydrate conference last year. USGS officials have agreed to allow Japan to drill two prototype wells on the hydrate-rich north slope of Alaska in 1998 in return for some usually proprietary Japanese technological data; and they have met with delegations from Russia, South Korea, Indonesia, Britain, and Germany. Indian scientists also have consulted with the USGS about exploring their country's continental margins. (So far, the main interest of U.S. companies in hydrates has been the possible danger. Occasionally, when crude petroleum is pumped through pressurized pipelines in cold climates, there is enough water and methane in the mix to form hydrates, which can plug the line. When dislodged, the plug may travel at the speed of a bullet, causing pipes to rupture or explode, and sometimes killing workers.)

The U.S. Navy also has shown interest. Hydrates change the acoustics of ocean bottoms in ways that can distort sonar signals used to track submarines. According to unclassified documents, researchers from the Naval Research Laboratory have been towing a new, 2,000-foot-long, deep-sea seismic apparatus over suspected hydrate sites to make better maps of them.

Anaerobic bacteria break down organic matter, producing methane for hydrates.



David Lindroth; after Keith Kvenvolden, USGS

Hydrate maps include inferred as well as known deposits, reflecting the still early stage of hydrate geology. Most hydrates are on the edges of continents in ocean settings (purple circles) and in permafrost (red diamonds).

Scientists are even looking to other planets. Based on pressure-temperature calculations, among other evidence, hydrates of carbon dioxide, methane, nitrogen, and ammonia are thought to make up some of the geology of icy moons orbiting Saturn, Uranus, and Neptune. They may exist on Mars. The earthly relevance: Our planet may have started out as a barren core of iron and silicate with no atmosphere, like a house without furniture. That's where the hydrates come in. They are good at trapping all kinds of molecules. Some scientists believe they are what comets are made of. Earth may have gotten some of its water, carbon compounds, and nitrogen—building blocks of life—when comets rained them down in hydrates, which then broke up into gases and water. The hydrates under the earth today are likely to remain as mysterious as these possible ancient ones. For now, we can only capture them briefly before they fizzle and disappear. □

Last year, parasitic mites and harsh winter weather eliminated 80 percent of the honeybee colonies in some parts of the country.

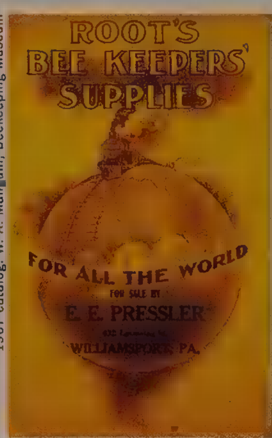
Trouble with Honeybees

Story by Sue Hubbell
Photographs by Gary Braasch

When European settlers arrived on the shores of North America in the seventeenth century and discovered to their dismay that there were no honeybees here, they set about importing them. Never mind that more than 3,500 species of native bees were buzzing about, energetically pollinating the native plants and the few crops—including squash and beans—grown by the people the settlers called Indians. Those bees do not produce useful amounts of wax or honey. Only honeybees do that, and without them the settlers lacked good-quality wax with which to make candles to light their dark days and darker nights and had to make do with myrtle wax or tallow from beef or deer. Without honeybees, they also lacked the major ingredient of mead, an alcoholic drink made from fermented honey and water. And last of all, they had no honey to sweeten their food.

The early settlers weren't interested in the pollination work that the native bees—or even honeybees—could do because they weren't aware of it. The role of insects in botanical fertilization was not clearly known until the late 1700s, long after the first recorded importation of European honeybees (*Apis mellifera*) to this continent. That report appears in a letter dated 1621 and written in the English office of the Virginia Company: "wee have by this shippe sent . . . fruit trees, as also pigeons . . . and bee hives . . . the preservation and increase hereof wee recommend unto you." If these bees survived the ocean voyage (of which there is no record), they would have prospered in Virginia and could have been the origin of swarms that spread westward in the following years. Sometime between 1630 and 1663, honeybees were also brought to New England to brighten the lives of colonials there.

Opposite: After hitching a ride on an adult honeybee, a parasitic mite (ticklike creature attached to the bee in the center of the photograph) will transfer to a brood cell and feed on the bee larva inside.



1907 catalog: W. A. Mangum; Beekeeping Museum

By 1800, swarming feral honeybees, nesting in tree hollows, had reached the Mississippi. In the 1850s, the bees were brought by ship to the West Coast, where their population was soon increased by bees carried overland by settlers, who kept them in cramped hives inside hollow logs. During the next half century, with the invention of better beekeeping equipment and the development of an industry to manufacture and sell it, honeybees, both feral and cared-for, were to be found throughout the United States.

Once the honeybees' role in pollination had been added to the list of their known virtues, farmers began setting out hives in orchards to increase fruit yield. But it wasn't until the present century, as agribusiness transformed farming in many parts of the country, that honeybee pollination services became a business as well. Tractors powered by internal combustion engines (already in use by the late 1800s) and the caterpillar tread (used in World War I tanks) may have given large-scale agriculture a push. The shortage of men to do heavy hand labor during World War II, the design of ever-more sophisticated farm machinery, and the development of pesticides all contributed to dramatic

Imported in the 1600s to provide colonists with honey and candle wax, honeybees a

changes in American agriculture. Farms became bigger, and machines took over much of the hard labor. Large plantings of single crops—monoculture—became the rule.

Beekeepers learned to take advantage of both mechanization and the growing agricultural need for pollination, and once again, the bee of choice was the honeybee. Many crops, especially those cultivated on a large scale—such as alfalfa and oranges—are not native to North America and may have bloom times that are more in sync with the population peaks of the introduced honeybee than with those of native species. In addition, most native bees fly no farther than 100 to 200 yards from their nests and have solitary nesting habits that make them harder to manage.

Grouping four or five hives of honeybees on a

pallet, modern beekeepers use forklifts and boom loaders to load and unload pallets from trailers, truck them from place to place as different crops come into bloom, and move on before the fields are sprayed with insecticides. The fee they receive for this service has become a more important source of income for some beekeepers than has honey. In recent decades, another, easily managed exotic bee—the alfalfa leaf-cutter bee—has come to play a significant role in commercial pollination, particularly of alfalfa. Together these two introduced bees account for about 90 percent of agribusiness crop pollination in the United States.

But now, the honeybees on which we have become so dependent are in trouble. In the spring of 1996, almond growers in California were advertising that they would pay $34

White Man's Fly

The story is often told by those who write about bees—I've told it myself—that North American Indians called honeybees "the white man's fly" because the bees, swarming ahead of the settlers, often invaded Indian lands before the pioneers. The phrase is always in quotes, as though it were a translation from some Indian language. It is a quotation, but from a literary white man, perhaps inspired by another literary white man, notoriously unreliable and romantic in his Indian lore.

In an 1879 essay on bees, John Burroughs wrote:

The Indian regarded the honey-bee as an ill-omen. She was the white man's fly. In fact she was the epitome of the white man himself. She has the white man's craftiness, his industry, his architectural skill, his neatness and love of system, his foresight; and above all, his eager, miserly habits. The honey-bee's great ambition is to lay up great stores.

Burroughs's metaphor—white man's fly—may have been inspired by a reading of the 1855 "The Song of Hiawatha," by Henry Wadsworth Longfellow. In this poem, the author's noble hero recites a dream he had about honeybees and plantain (an introduced European weed he called by the common name, white man's foot) to foretell the coming of whites. Hiawatha recommends that the whites be received with Christian resignation and then makes his lugubrious exit by canoe into the sunset. Of the white men, Hiawatha said he dreamed:

Wheresoe'er they move, before them
Swarms the stinging fly, the Ahmo,
Swarms the bee, the honey-maker;
Wheresoe'er they tread, beneath them
Springs a flower unknown among us,
Springs the White-man's Foot in blossom.

S. H.

now responsible for most agribusiness crop pollination in the United States.

per colony for beekeepers to bring honeybees to their trees. This is up from the $22 per colony that beekeepers were charging in the 1980s. In Maine, it was hard to find honeybees at any price last year.

Like all animals, honeybees get sick and have parasites, but over the years, beekeepers had learned how to help their bees stay healthy. Once a disease or pest takes hold in any large population, however, it can spread rapidly. In the last fifteen years, two particularly devastating species of parasitic mites have shown up in American hives. One, *Varroa jacobsoni,* parasitizes bee larvae; the other, *Acarapis woodi,* infests the trachea of adult bees. Treatments have been far from perfect; *V. jacobsoni* has begun to show resistance to the chemical American beekeepers have been using to fight it, and breeders have so far failed to develop a totally mite-resistant bee.

Rough estimates suggest that last year the mites, together with harsh winter weather, may have eliminated 80 percent of the honeybee colonies in some parts of the country. In the part of the Ozarks where I kept bees for twenty-five years, only a few hives, and apparently no feral honeybees, survive. Ten or twelve years ago, it was the rule of thumb in this part of southern Missouri that there were approximately as many feral honeybees—living in tree holes and under the sides of abandoned buildings—as hived ones, and that the feral bees, along with native bees, were doing a lot of pollination for free.

In Missouri, where farming is a matter of raising cattle, a nice stand of white clover in a pasture is appreciated. There are also a few orchards in the state. Today, farmers tell me that their white clover and fruit are the poorer for the lack of honeybees. In talking to other beekeepers and researchers around the United States, I frequently hear the same story. Many beekeepers, discouraged by the expense of replenishing their stocks of bees each spring and the growing inutility of antimite treatments, are leaving the business.

Above: Beekeepers use smoke to make honeybees easier to manage. "Thinking" they must flee their burning home, the worker bees rush to eat as much stored honey as they can, and a bee with a full stomach is a calm bee. Opposite: Researcher Suzanne Batra, top, inspects a polyester bee on a tulip tree flower. The underground brood cells of these bees, bottom, resemble little plastic bags.

The picture is not completely bleak, however. Scientists are working hard to understand the life cycles of the parasitic mites and to develop mite repellents and pesticides. Some biologists are hopeful that bee behavior can be brought into play—perhaps bees can be bred that will get rid of the mites by grooming one another or by removing infected pupae from the colony. A series of mild winters might also help the bees survive future mite attacks.

Meanwhile, researchers are beginning to take considerable interest in both our native bees and a handful of species imported as crop pollinators. Now there is a fledgling industry in these bees—called pollen bees to distinguish them from honeybees.

Unlike the social honeybees and, to a lesser extent, bumblebees, which nest in large colonies and divide themselves up into castes, each with a different job to do, most of North American native pollen bees are solitary. Each mated female solitary bee makes her own nest—with about ten brood cells—in a hole in the ground or, depending on the species, in a stem, post, or rotting tree. She builds her nest brood cell by brood cell, provisioning each cell with a mixture of nectar and pollen, laying a single egg in it, and then sealing it off before moving on to make the next one.

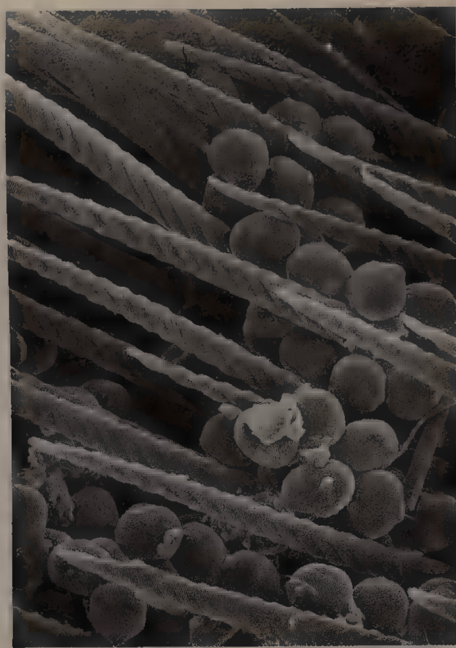
Solitary bees range widely in size: the smallest North American species, *Perdita minima,* is about the size of a fruit fly; tropical carpenter bees may reach an inch and a half in body length. Many are generalists; some are specialists: squash bees, a species of miner bee, work American native gourds; another kind of

With honeybee numbers in decline, pollination researchers are taking a closer look a

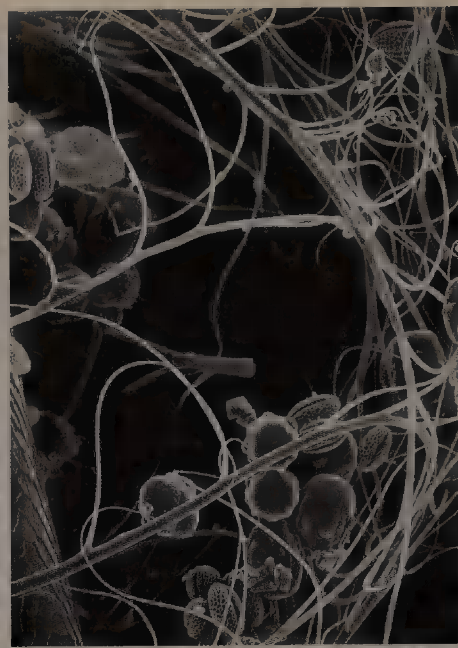
miner bee prefers wild morning glories; an oil bee of the genus *Macropis* loves the oil of *lysimachia*, wild yellow loosestrife (oil bees mix plant oils, not nectar, with pollen for their young); and some night-flying sweat bees pollinate evening primroses.

One question of interest to many researchers today is how the native pollen bees may have been affected by human activities—especially those associated with agriculture—and by competition with the honeybees. I asked Charles Michener, of the University of Kansas, the grand old man of American bee and pollen studies, what he thought. "Well," he said, "disturbed land and bare ground created by humans are better for wild bees than undisturbed, wooded land. Bees like open, sunny places." Michener added that in 1983, some of his students compared disturbed land near Lawrence, Kansas, with pristine areas nearby and found not only more individual bees on the former but also more species of bees. And he cited an unpublished 1972 study by the Illinois Natural History Survey, which found the same 220 species of bees living in an area near Carlinville, Illinois, that had been there in the early 1900s. Michener cautions, however, that this was a study of a single, small area, and that the original data were collected long after the introduction of honeybees. He also makes the point that it is difficult to come up with an accurate assessment of the effect that humans and imported honeybees have had on native species without a census of the number and diversity of bees before settlers arrived. "Very little work on this important matter has been done, except in Australia," he said. "David Roubik also has some data from South America."

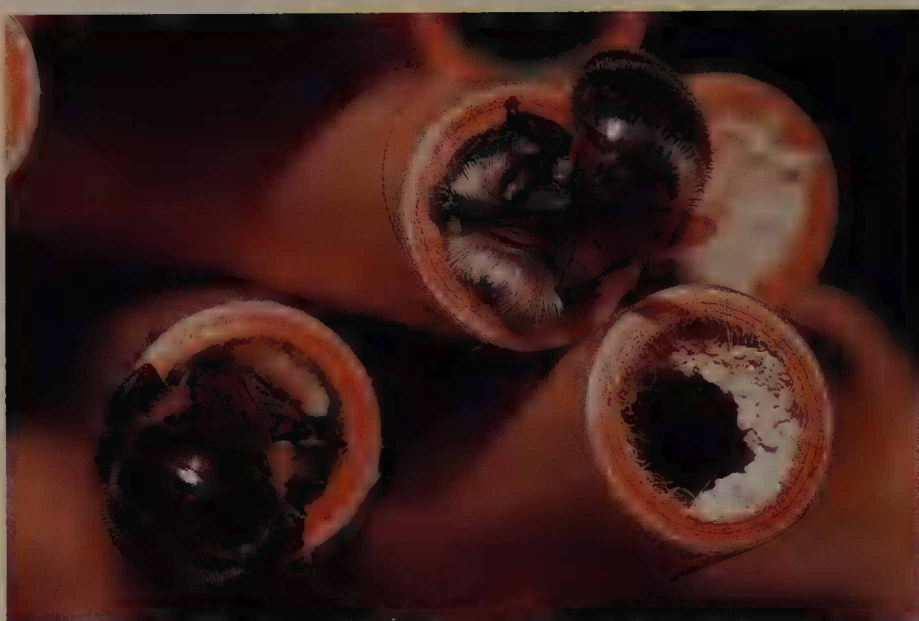
The Australian work, I discovered, suggests that honeybees, which were introduced to that continent 150 years ago, may displace native pollinators—birds as well as bees—from flowers. Honeyeaters, for example, birds with long, slender bills, visited flowers less often when honeybees were active and tended to concentrate on those flowers least used by the honeybees. Meanwhile, some studies suggest that the introduced honeybees do not always pollinate native plants effectively, which may lead to the production of fewer fruits.



Suzanne Batra (X 500)



Suzanne Batra (X 440)



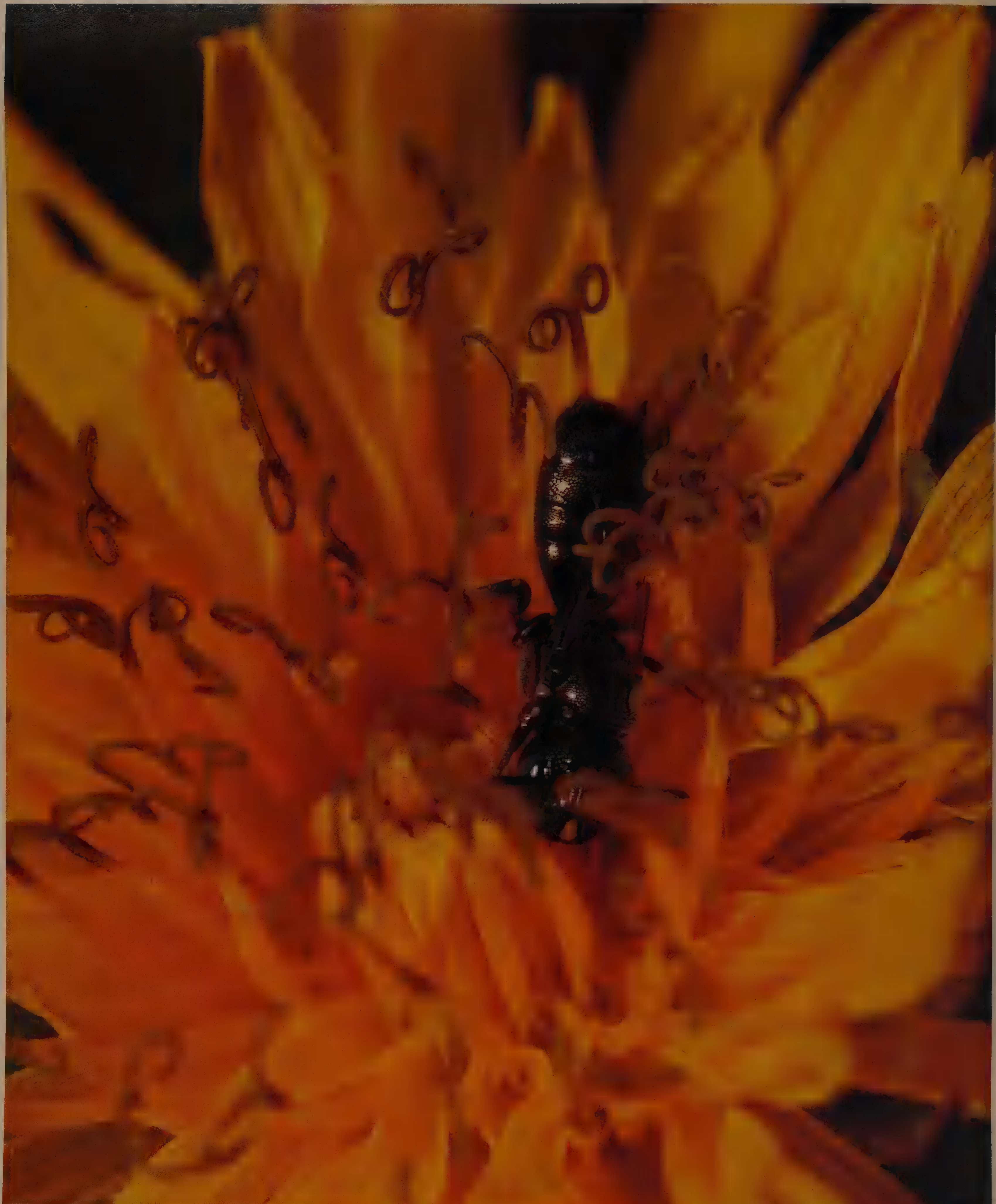
Pollen is caught in the ridged hairs, top left, of a leaf-cutter bee and the feathery hairs, top right, of a sweat bee. Above: Female bullheaded mason bees seal off the entrances to their cardboard-tube nests, after filling them with brood cells made of mud and bits of leaves. Sometimes mistaken for bees, hoverflies, opposite, have only one pair of wings and are much less effective pollinators.

I reached David Roubik at his office in Panama, where he is a scientist with the Smithsonian Tropical Research Institute. "I've studied bees in Mexico, Panama, and French Guiana," he told me, "and have good data on the population dynamics of native bees for seventeen years." The situation is complicated in the Tropics by the presence of native bees that, like honeybees, produce and store honey. There are also hundreds of thousands of flowers for the bees to visit. Roubik suggests that the honeybees may be able to outcompete the native bees (both honey producing and solitary) because they forage over greater distances and, if necessary, can move their colonies. Roubik adds, "It is interesting to note that there are fewer bee genera in the Old World, where honeybees have been for a long time, than in the New World, where they have been for only a short time."

Suzanne Batra, bee scientist with the U.S. Department of Agriculture, offers a different explanation: "I think the different number of genera reflects past climatic differences. While it is reasonable to think that exotic honeybees will compete for pollen and nectar with native species, there are as yet no hard data, and I am not convinced that competition is as important as some people think it is." I visit Batra, a vibrant woman with her hair in a single long braid, at her office in

orth America's 3,500 species of native bees—as well as a few imported varieties.

A few scientists, skittish about bringing new insect species into the Americas, wou



ke pollination research restricted to native bees. Others see no reason for alarm.

Beltsville, Maryland. A field biologist with much experience studying pollen bees in Asia, where several native species of honeybees are abundant, she is impatient at being held inside on rainy day. Her room is a zestful clutter of files, magazines, technical papers, cartoons, and photographs. Stacked papers threaten to swamp the postage-stamp-size open space on her desk. From one stack, she pulls out a diagram from a population study on a wide variety of species of East Coast pollen bees and shows me that their numbers are high very early in the springtime, when they emerge, mate, provision their nests, and lay their eggs. The adult population plunges by late May, just as the dense forest canopy leafs out, most forest flowers finish blooming, and honeybee numbers are building, indicating that they do not feed on the same flowers. Currently, Batra is working with a species of ground-nesting *Andrena* bees that are important pollinators of red maples, pear trees, and early-blooming wildflowers. These native bees are so tolerant of the cold that they emerge from their nests as the snow melts in February, long before other, warmth-loving bees are able to fly.

Above: Sun hat, net, and collecting bag are all Suzanne Batra needs for a day's work. Opposite: Related to carpenter bees, Ceratina *pollinate dandelions and many garden flowers.*

Further evidence that native bees can hold their own against honeybees comes from random samples Batra and Edward Barrows, of Georgetown University, took in some West Virginia woods in 1991. The year's catch turned up only 34 honeybees and 1,701 native pollen bees. The proportions were similar in 1992 and 1993 catches. Recently, Batra has also taken random samples near her laboratory in Maryland, where there are numerous, healthy honeybee hives (part of the Department of Agriculture's research on the troublesome mites). Even there, of the bees caught in sweeps around fruit trees and blooming wildflowers, only about 10 percent are honeybees; the rest are all pollen bees.

19th-century books: W. A. Mangum; Beekeeping Museum

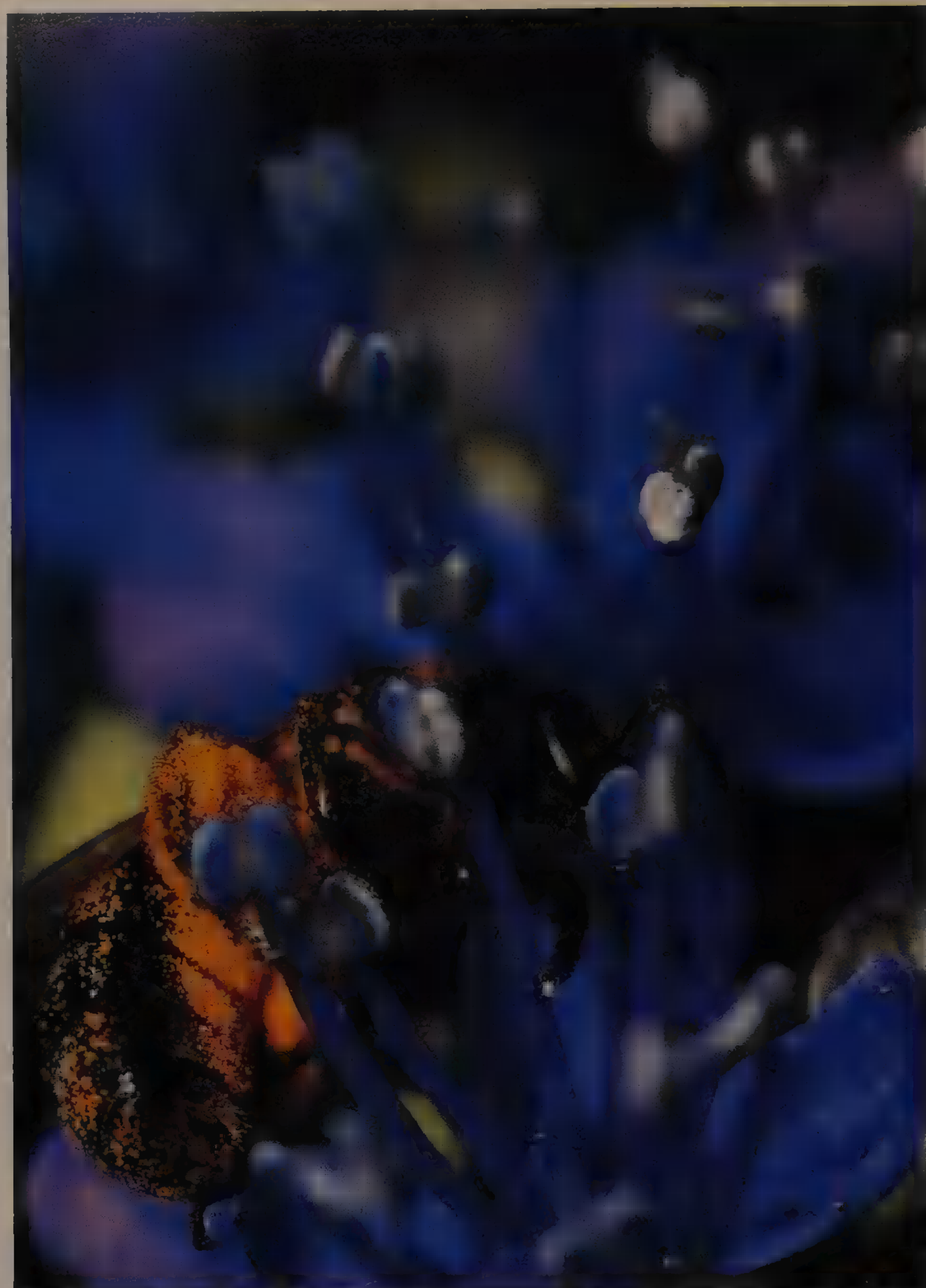
Batra points out, however, that native bees in other environments may be more vulnerable to competition with honeybees if they are more abundant. One experimental study in Arizona, conducted by ecologist William Schaffer and entomologist Stephen Buchmann, both of the University of Arizona, suggests that honeybees can have a significant, adverse effect on native pollinators of shindagger, a native species of century plant.

Until more data are in, Batra, for one, does not see cause for undue alarm on the subject of honeybee–native bee competition. She also agrees with Michener that humans have made good habitat for native bees by clearing the land and opening up the dense forests that originally covered much of eastern and central North America. In addition, crops and ornamental plants in medium-size clearings and meadows have given the bees new sources of food. But, she adds, some agricultural practices, especially those associated with large-scale agribusiness—such as the elimination of hedgerows, irrigation (which floods the cells of ground-nesting bees), and the use of insecticides—may prove harmful to our native bees. "Some species have benefited from us; some have not," she concludes.

Batra hopes that the more that researchers and farmers learn about pollen bees—native and imported—the more they will want to employ them, and that with greater commercial use may come changes in agricultural practices beneficial to the bees. She shows me the plastic nest boxes now being sold for keeping one familiar pollen bee—the bumblebee, which sometimes out-pollinates the honeybee ten to one. For some crops, such as red clover, bumblebees are the most important pollinator. The nectar-bearing part of

Some bees may visit more than 300,000 flowers during their brief adult lives.

the red clover blossom is too deep for a honeybee's tongue; the bigger bumblebees have longer tongues and happily apply themselves to the blooms. Several challenges remain, however, before bumblebee pollination can become commercially economical outside of the greenhouse. Bumblebee colonies do not endure from year to year; they are tricky to raise artificially and, although costs are coming down, currently expensive for farmers to bring to their fields.



Sweat bees—many just a quarter of an inch long—can carry impressive amounts of pollen, above. Opposite: A Lasioglossum *sweat bee forages on a privet blossom.*

At last the rain breaks, and Batra takes me outside to show me a few of the other species that show promise as agricultural pollinators. Some, like the shaggy fuzzyfoot bees nesting in dry adobe blocks near her lab, are imported. About the size of honeybees but fatter and darker, these Japanese bees (*Anthopora pilipes villosula*) are active and fast flyers on this cool, gloomy day, which is too inclement for honeybees and native bees. Nearby, Batra and I look at nest setups for some other species: drilled slabs of wood, looking like giant cribbage boards, for alfalfa leaf-cutter bees; bent cardboard tubes for a variety of mason bees. Then we walk down a woodland path to see the ground nests of what Batra has named polyester bees. To keep their brood cells from getting damp, the three species of native polyester bees nesting in the sandy soil beside the path waterproof their cells with a thin transparent film, made from polyester, which they secrete from a gland in the abdomen. The weather today has kept these bees inside their closely grouped nests, but a few have been at work carrying grains of sand to the surface and arranging them around their holes. When we return to her office, Batra shows me a liner she excavated from a polyester bee cell. With an extra flap on the top, with which the female closes the cell after she has laid her egg, the transparent liner looks for all the world like a Ziploc bag.

1887 advertisement: W. A. Magnum; Beekeeping Museum

The polyester and other native ground-nesting bees contribute greatly to the pollination of both wild plants and crops grown on small farms and in home gardens, but they are difficult to manage on the scale required by agribusiness. They can seldom be attracted to artificial nesting spots, and it would require a great deal of hand labor to go about with a shovel digging up their nests. But research goes on, with some notable successes. Growers, for example, have managed to establish beds of a special soil that is acceptable to the ground-nesting alkali bee, which is sometimes used for alfalfa pollination in the West. Unfortunately, their success has led to new problems: the unnaturally dense populations of alkali bees nesting in these beds have proved especially vulnerable to their natural enemies, which include fungi, other microorganisms, and parasitic insects.

Partly because of the difficulties of "domesticating" our native solitary bees, Batra sometimes chafes under the recent regulatory climate that restricts her experiments with selected, manageable, imported pollen bees. Some scientists, worried about possible negative effects of introduced bees on native species, would like to see the research limited to native species. Batra's work is to develop a stable of bees that are inexpensive and easy to manage, and she suspects that some of the best candidates may come from other countries, where our major agricultural crops come from as well. "Some people have a prejudice against exotics," she says. "It is an anti-immigrant feeling. But, after all, most of our crops, livestock, and we ourselves are exotics, and honeybees were also imported. I think there is a need, and room, for many kinds of helpful bees." □

About 85 percent of North America's native bees lead solitary lives, nesting i

By Suzanne Batra

Unsung Heroine

Most of North America's 3,500 species of bees go unnoticed, primarily because people expect all bees—apart from the big, conspicuous bumblebees and carpenter bees—to resemble the familiar honeybee. In fact, many are smaller, looking more like wasps, fuzzy flies, or flying ants than honeybees. Their behavior, more than their appearance, is what gives them away: if you see an insect on a flower deliberately packing pollen onto its hind legs or under its abdomen, it's bound to be a bee.

Once you know what to look for, the abundance of bees can be impressive. On a warm day in June, a typical backyard garden in the northeastern United States may contain some thirty species and hundreds of individuals. Native bees (primarily the females, with a little help from the males) and other flower-visiting insects can usually meet the pollination needs of gardens and most small farms. Agribusiness, in contrast, depends on the use of additional pollinators, traditionally the introduced honeybee. With the recent, devastating decline in honeybee numbers, however—and the growing recognition that for some crops, other bees may do a better job—researchers are looking at other species, now commonly referred to as pollen bees.

Several factors are critical for developing a bee into a manageable pollinator for agribusiness crops: it must be willing to nest under crowded conditions with others of its kind; its brief adult life, which lasts just a few weeks, must coincide with the flowering of the crop plant; it must prefer the crop flowers to those of other plants so it won't wander away; its foraging style and body shape should result in efficient cross pollination; it must be able to raise its brood on the nectar and pollen produced by flowers; and its natural enemies must be controllable.

Whatever their commercial prospects, of course, all pollen bees are vital members of their natural habitats and deserve protection.


Gary Braasch
Honeybee


Gary Braasch
Bumblebee


Ken Brate; Photo Researchers Inc.
Carpenter bee


Gary Braasch
Mason bee

Bumblebees These big, fuzzy bees (genus *Bombus,* with forty-six species in North America) are important pollinators in cold climates. Most are social, forming small colonies with queens and workers and often nesting underground in abandoned mouse nests. Only young mated queens survive the winter to start new colonies in the spring. Some species make no nests but instead, like cuckoos, lay their eggs in the nests of other bumblebees.

Ever since methods of keeping bumblebee colonies year-round were developed ten years ago, the business of raising these bees—which are in demand to pollinate valuable greenhouse-grown crops—has been thriving in several countries. Bumblebees adapt to being confined inside a greenhouse, while honeybees try to get out, banging against the glass ceiling and generally winding up dead on the floor. Another commercial advantage of bumblebees is that they can pollinate certain plants, such as hothouse tomatoes, very fast, vibrating their bodies so rapidly that they literally "buzz" the pollen out of the flowers.

Carpenter bees Big and solitary, carpenter bees (genus *Xylocopa*) resemble bumblebees but are not closely related to them. Most are tropical; only eight species live in North America, where they pollinate many wildflowers and crops. The flowers of passionfruit (including the North American maypop) are structurally adapted for pollination by the big carpenter bees; smaller bees simply fail to trigger the flower's pollination mechanisms. Plants of horticultural interest pollinated by carpenter bees include our native catalpa trees and wisteria, which is native to China and Japan.

Male carpenter bees maintain territories around nests and flowers, where they hover, occasionally darting away to fight with an intruding male or to pursue a female. Mated females make their brood cells inside tunnels that they chew in soft, dry woods and often—unfortunately—houses. (Their nests are easily recognized by the neat round hole at each entrance; reaming and plugging up the holes may encourage the bees to nest elsewhere.) Sometimes, young adult daughter bees stay in their natal nests with their mother for a while, suggesting that, given enough time, these bees might evolve into social species.

Mason bees About 140 species of these solitary bees live in North America, primarily in the West. Most are blue or green in color and are active in spring. Females carry pollen beneath their abdomens, instead of on their hind legs as most bees do. Mason bees (*Osmia*)

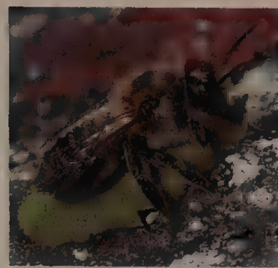
e ground, hollow plant stems, holes left by other insects, or wooden buildings.

nest in preexisting holes—both natural ones made by beetles or other insects and artificial ones, such as nail holes. Their brood cells, made of mud and sometimes masticated leaves, are lined up in the holes. Several species of mason bees have been used to pollinate fruit trees and have proved very efficient: three or four females per tree will suffice. Also efficient and easy to care for, the hornfaced bee (*O. cornifrons*) has been used for about sixty years to pollinate apple trees in Japan, where it is often preferred over the honeybee.

Leaf-cutter bees These solitary, usually grayish bees (*Megachile*) live worldwide, with about 120 species in North America. Most are active in midsummer. Like mason bees, they usually nest in preexisting holes and carry their pollen loads under their abdomens. Their brood cells are made of bits of leaves and petals, cut by the nesting female. Agriculturally, the most important is the introduced Eurasian alfalfa leaf-cutter bee (*M. rotundata*), raised by the millions to pollinate alfalfa, the United States' most valuable livestock forage crop.

Mining mud bees About sixty species of these rotund, fast-flying, solitary bees (*Anthopora*) are found in North America, mostly in the West. The females usually dig their nest tunnels in the dry clay of cliffs and adobe walls. Some species make a hollow chimney of dried mud that conceals the nest entrance. After making each brood cell out of mud, the female lines it with a fatty material secreted from a large gland in her abdomen. She adds this energy-rich, fatty substance to the nectar and pollen she provides for the larvae. To meet her own high energy needs and those of her brood, a female mud bee may visit 337,000 flowers during her six-week-long adult life (during the same time period, an individual honeybee might visit perhaps one-tenth as many flowers). Whether zooming from flower to flower or hovering in front of one while probing for hidden nectaries with their long tongues, these bees are reminiscent of hummingbirds and hawkmoths. Two mining mud bees—*A. abrupta* and *A. pilipes villosula*—are now being tested as possible pollinators of fruit crops.

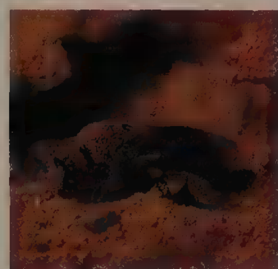
Polyester bees These solitary bees (*Colletes*) dig nests and cavities for brood cells in the ground, then line the cell cavities with an abdominal secretion that solidifies


im Taylor; Bruce Coleman Inc.

Leaf-cutter bee


Gary Braasch

Mining mud bee


Gary Braasch

Polyester bee


Gary Braasch

Digger bee


Gary Braasch

Sweat bee

to form a transparent, waterproof, polyester membrane. Nests may be close together, numbering in the thousands in some locations. About one hundred species of polyester bees—each with its own flower preferences—live in North America; some are excellent blueberry pollinators. As yet, there is no commercial use of polyester bees, but preliminary trials suggest that they could be induced to nest in artificial "bee beds."

Digger bees With some 500 species in North America, and many more elsewhere in the Northern Hemisphere, these usually drab and small solitary bees (*Andrena*) are rarely noticed but may be our most abundant bees. Digger bees make burrows and cells underground and often hide the entrances to their nests beneath leaf litter or in grass to evade their many enemies, which include parasitic flies and cuckoo bees.

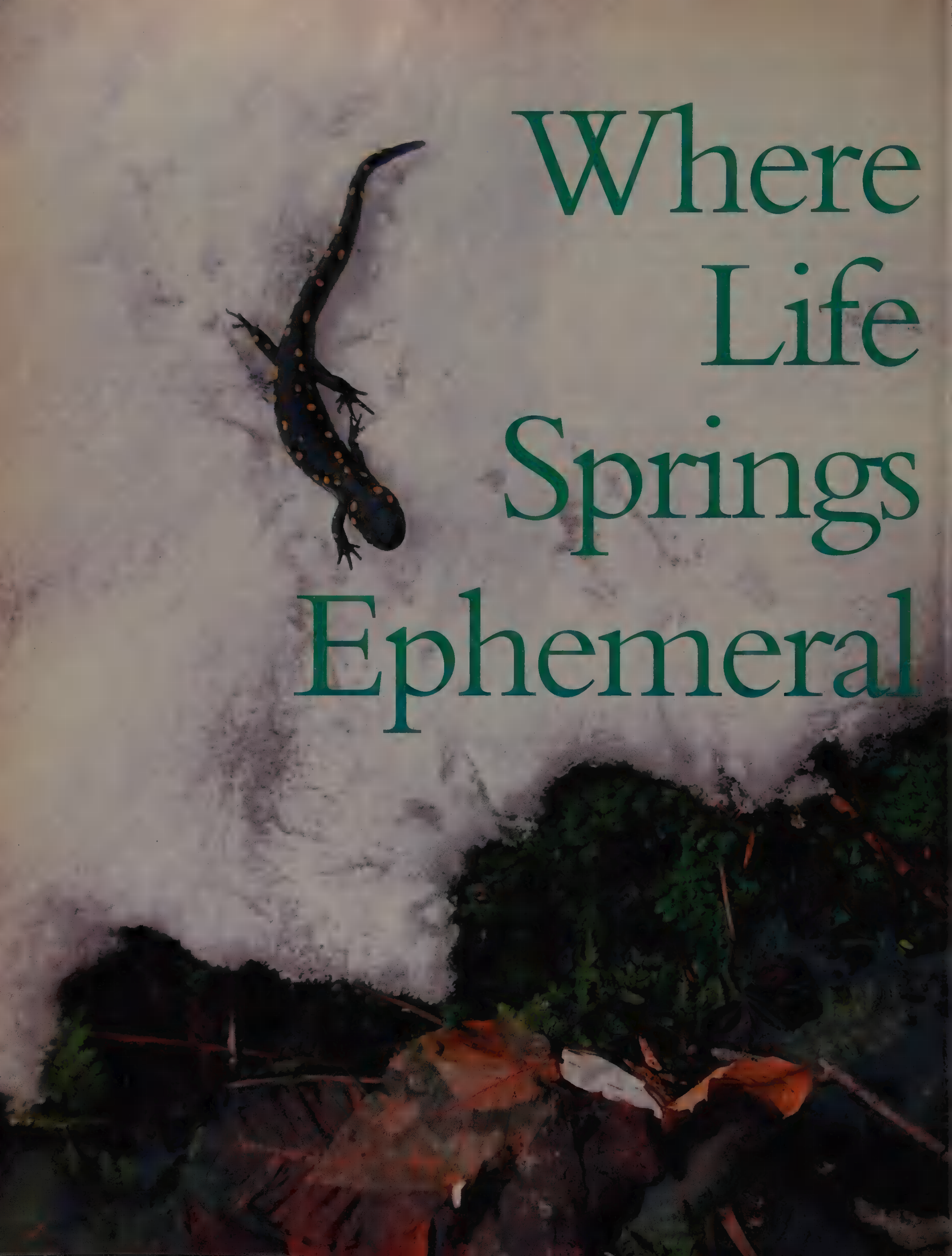
Most digger bees are active in spring, when they pollinate various wildflowers, trees, and fruit crops. They are especially valuable in orchards because they carry large, loose loads of pollen, which are spread widely among the flowers as the bees fly from tree to tree. These bees are very vulnerable to agribusiness practices such as irrigation, clean cultivation, and pesticides. So far, efforts to manage them have failed, and the best way to preserve them—and continue to reap the benefits of their pollination services—is to preserve wild land (around orchards, for example).

Sweat bees These small bees get their common name from their attraction to hot, salty perspiration. When they land on human skin, they walk around, licking and tickling. Brushed away, they return; swatted, they sting. Sweat bees (several genera in the family Halictidae) live worldwide, with about 500 species in North America. They are usually dark, although some species are bright green. Most nest underground, often with many nests in one small area.

Sweat bees are unusual because, depending on the species, they may either be solitary or have various cooperative nesting arrangements, including nests with more than one queen and up to hundreds of workers. Cuckoo sweat bees lay their eggs in the nests of others. The alkali bee (*Nomia melanderi*), a turquoise-banded solitary species, is used commercially to pollinate alfalfa in the West. □

of Pollination

Where Life Springs Ephemeral



Vernal pools are here today, gone tomorrow, and back again next year.

By Mark P. DesMeules and Philip Nothnagle
Photographs by Gustav W. Verderber

Equipped with rain gear, headlamps, and hip waders, we walk through the Vermont woods on a dark, rainy night in late March. The air temperature is about forty-five degrees, and ground fog gathers in low places, helping to melt the patches of snow that remain from winter. We hear the call of a spring peeper and are startled by a bolting deer, then pause when one of our headlamps lights up the wet ground: three glistening salamanders are methodically walking ahead of us on the forest floor. About ten inches long, these purple-black creatures splotched with large yellow spots are rarely seen in daylight. They are moving slowly, joining others of their kind in a trek to their ancestral pond to breed.

A few yards ahead, we hear the cackling of wood frogs amid some hemlock trees, then arrive at a pool some forty feet long by forty feet wide and three or four feet deep. Dozens of yellow-spotted salamanders are resting on its leaf-covered bottom. On the surface, others are swimming in spirals, some nudging or clasping a mate. The annual congress at the vernal pool is in session.

Fed by snow and winter rains, vernal pools fill when spring arrives, then dry up again by early summer. Also known as temporary, or ephemeral, ponds, vernal pools have as their primary ecological characteristic a certain predictable unpredictability, supporting a community of plants and animals that come together for several months each year. Although they attract occasional dragonfly nymphs and other insect predators, vernal pools are bereft of fishes. Therefore, they are havens in which many small creatures can thrive and lay their eggs in comparative safety.

A yellow-spotted salamander, opposite page, crosses melting snow to reach its breeding pool. In spring, a vernal pool in the woods near Norwich, Vermont, left, has filled with meltwaters and is teeming with life. Right: By summer, the same pool has evaporated.

Vernal pools are found throughout North America and have been reported from places as far afield as Spain and South Africa. They are usually about twenty-five by seventy-five feet and generally under four feet deep, draining water from a surrounding area approximately four or five times the size of the pool. No doubt even larger ones exist.

For a vernal pool to form, an unusual combination of conditions must be in place. The first is a depression in the terrain with neither a permanent inlet nor an outlet. A source of water is necessary, usually from spring rains and melting snow. If too much water comes in, the pool may become permanent; if too much drains out, it cannot form. Finally, the ground must have poor drainage and a relatively impermeable substrate, such as rock, clay, or a mixture of compacted sand and clay, to hold the water until warm weather causes it to evaporate.

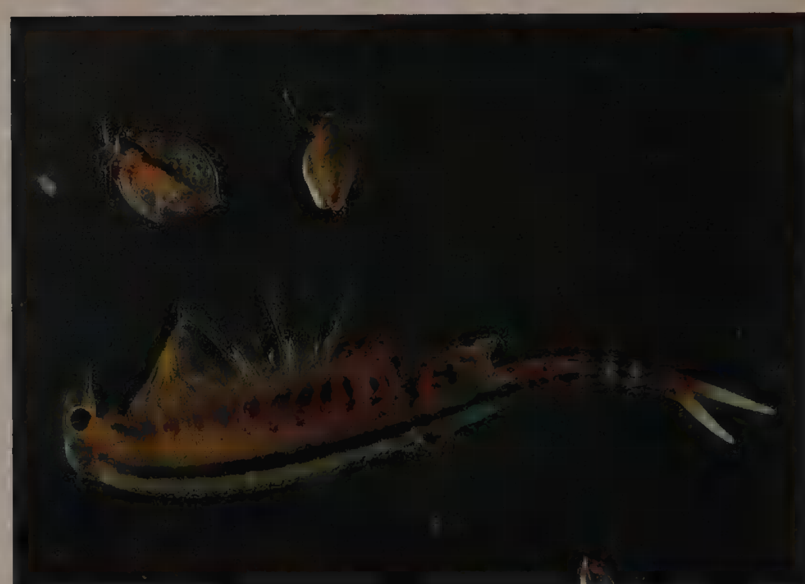
Seasonal pools in every region of the country function in similar ways. The particular species that occupy the pools change from north to south and from east to west. But fairy shrimps, fingernail clams, and several kinds of amphibians, as well as a community of other tiny invertebrates (water fleas, copepods), are always present; predatory fishes are absent. Thus, if the inhabitants can speed their development in the several weeks to a few months that a vernal pool exists, they will not have to encounter predators that inhabit lakes and streams.

In a Vermont vernal pool, the flow of energy typically begins with detritus—the dead and decaying organic material that accumulates in standing water. When

these leaves, twigs, and other remains decay, they release nutrients that feed microscopic animals, bacteria, and algae. One life form becomes the basis for the next in these pools.

By the time wood frogs, tadpoles, and the larvae of spotted and Jefferson salamanders emerge from their gelatinous eggs, a layer of algae has already spread over the submerged leaves, rocks, and twigs. Since these amphibians begin as algae feeders, they have little trouble finding green pastures on which to graze. Fairy shrimp eggs, dormant throughout the winter months, hatch and release fully developed nauplii (free-swimming larvae). These begin their lives as filter feeders, capturing a variety of microscopic plants and animals in the newly filled vernal ponds.

One amphibian predator that seems to have evolved to exploit the early emer-



gence of the fairy shrimps (and sometimes wood frog larvae) is the marbled salamander. Individual salamanders arrive and pair off in September to lay their eggs in the moist detritus left behind by the evaporated pool. The female excavates an oval-shaped burrow and lays approximately 200 eggs, which (depending on weather conditions) may either hatch that fall or remain dormant until the following spring. The marbled salamander has thus been able to hedge its bets about when the pool fills and can generally mature before the pool's other amphibian inhabitants. This strategy both increases the availability of food and reduces the risk that the salamander's larvae will end up stranded when the pool dries.

Vernal pool organisms must also be able to survive the dry seasons of the year. Canadian ecologist Glenn Wiggins and his colleagues have identified two basic strategies that the aquatic creatures use to avoid desiccation when the pools dry: they must either disperse or go into a dormant state. Fingernail clams, snails, and fairy shrimps generally enter diapause, a resting stage—some as eggs, others as larvae or adults. Resistant to both drought and freezing, fairy shrimp eggs can remain viable for many years. Since the development of their eggs in vernal pools depends on changes in water and oxygen levels, fairy shrimp larvae usually hatch early in the season, so they can complete their life cycles before insect predators arrive. If the pool disappears, so will the adult fairy shrimps.

Mayflies and midges come to the pools in spring to lay their eggs, then fly away; Mosquitoes, caddis flies, and damselflies deposit their eggs in the mud after the

water has disappeared. All these eggs will hatch into larvae in late winter and spring, when the pool fills.

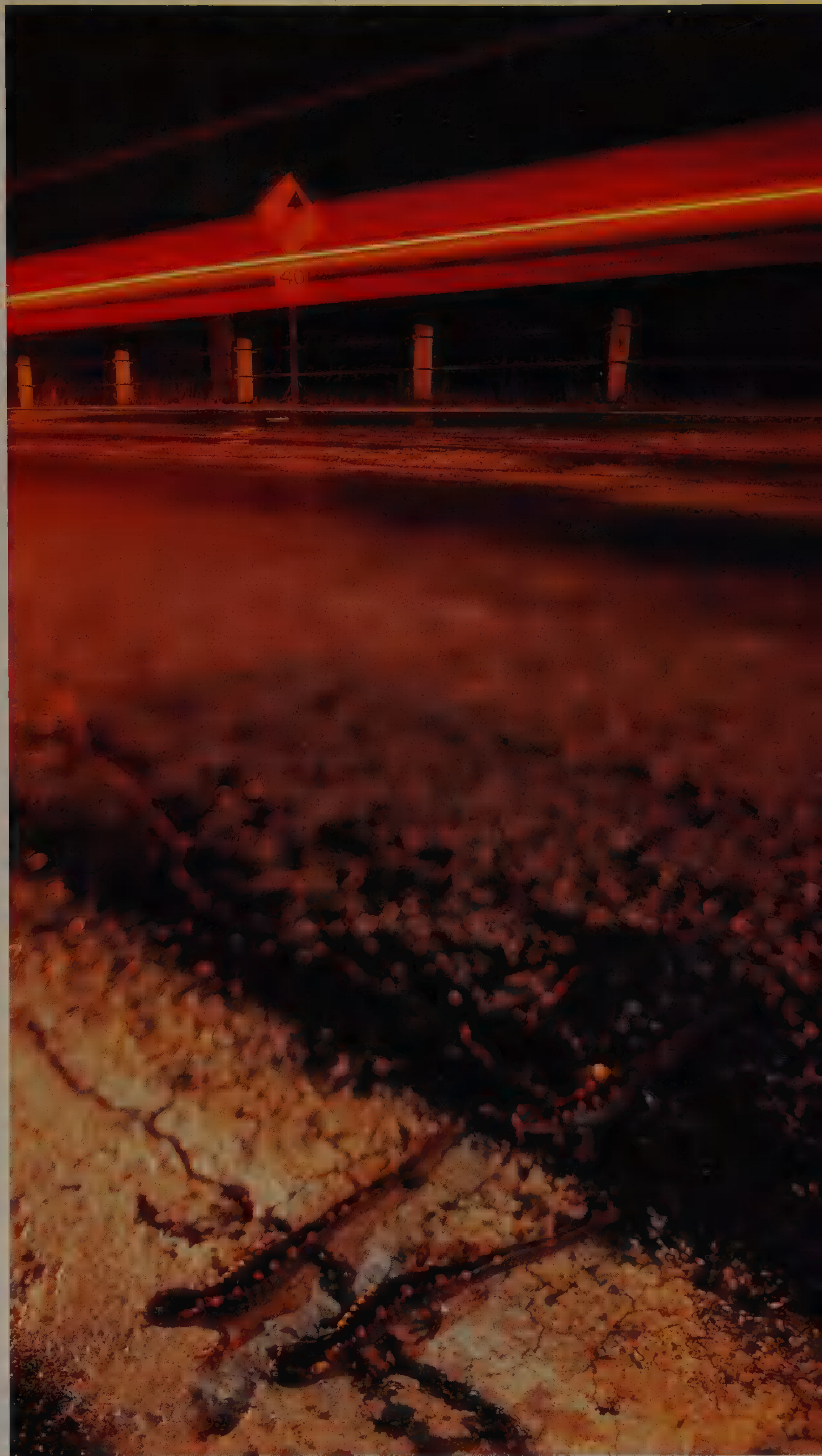
Amphibians, such as salamanders and wood frogs, disperse when the pool evaporates, then return to lay their eggs in spring after it has filled. Spotted salamanders exhibit a remarkable fidelity to their breeding pools, often returning to the same place year after year. If their pool is paved over or filled in, they may not be able to breed at all.

A few states, notably California and Massachusetts, have begun to take steps to protect vernal pool communities—but their ephemeral nature makes these little ecosystems difficult to identify. While a bog or a swamp can be easily spotted at almost any time of year, a dried vernal pool requires some expertise to locate out of season. (A reliable test is to sample the soil at a suspected depression. Most forest

An adult yellow-spotted salamander, top left, perches near its cluster of eggs. A wood frog, far left, perches on an oak leaf amid the patchy ice of a vernal pool. Fairy shrimps and other small invertebrates, left, hatch from eggs that have overwintered in the mud of dried pools. Right: Yellow salamanders complete a dangerous crossing on their way to a pool in spring. The red streaks are the taillights of passing automobiles. Some states have provided tunnels under such roads to facilitate safe crossings by small animals.

soils are gray to brown, with some reddish color from oxidation. Under a vernal pool, there is only a characteristic, anoxic black muck called hydric soil.)

Defined as much by their absence as by their presence, vernal pools are wetlands that are mostly not wet: here today, gone tomorrow, and back again next year. Just as bogs and other valuable wetlands became recognized as much more than "swamps" and "barrens" some twenty years ago, so are vernal pools only now becoming appreciated for their ecological importance and richness. □



EXPO'98

The blues that adorn the white houses of Obidos, 50 miles from Lisbon, are typical examples of local color. It´s a feature beautiful enough to have been the inspiration behind a few songs and not all of them sad. But the painting is only one example of the area´s inspirational beauty. Flower-laden windows, narrow stone streets, sun-drenched squares and a medieval castle, now a magnificent "Pousada," add color too. In other regions, such as Alentejo, white-and-blue houses prevail, where they contrast with the wheat-covered plains, the shadowy peace of the holm oak trees and the coolness of olive groves. Of course, it would be easy for us to go on singing the praises of Portugal. After a visit you´ll be tempted to write a few verses of your own.

Obidos

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This Land/New Brunswick, Canada

Bay Leaves

By Robert H. Mohlenbrock

In August 1995, my wife and I visited the village of Saint Martins, located on the Bay of Fundy in the Canadian province of New Brunswick. After spending a comfortable night at a bed and breakfast, we were ready for a day of exploration. Our first destination was the mouth of the Big Salmon River, a few miles east. Setting out on a country road, we passed over a covered bridge that spans a tributary of the local watercourse, the Irish River. Just beyond, we viewed the storied red sea caves of Saint Martins, large overhangs in the red conglomerate cliffs that have been eroded by the bay's gigantic tides. If the tide had been out, we could have walked one hundred feet or so into the sea caves.

Continuing on toward the Big Salmon River, we entered a lowland forest containing a mixture of conifers and hardwoods. Among the most common trees were red spruce and balsam fir, species that are recovering after having been ravaged by spruce budworms between 1969 and 1982. The budworms (larvae of the moth *Choristoneura fumiferana*) are active in late April and early May, entering the opening buds of the trees to feed on the

[illegible] National Park. Photograph [illegible]

new growth of needles. With dense fog, cool summers, and the absence of fire for nearly two hundred years, conditions had been ripe for an explosion of these insects. As trees died by the hundreds, the forest opened up, providing optimal habitat for white-tailed deer. Now, however, with young spruces and firs growing back, the deer are gradually leaving, and moose, which prefer dense growth, are returning.

Also present in the forest is mountain birch, a species more typical of high-elevation habitats but which thrives in the cool, moist conditions that prevail around the Bay of Fundy. Several of the mountain birches we saw were dead or dying, however, apparently because of sensitivity to acid fog. Heavy fog frequently rolls in from the bay, carrying sulfurous vapor emitted from paper mills in Saint John, some thirty-five miles away.

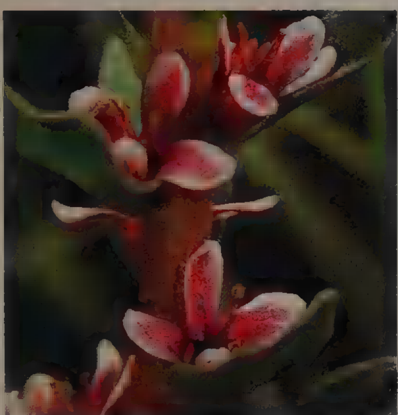
Our road ended at the mouth of the Big Salmon River. At the time, the waters were tranquil, but in spring, following snowmelt and spring rains, the river fluctuates violently, scouring the bouldery bank and the vegetation that grows among the rocks. The 150-mile-long Big Salmon River drops rapidly from highlands 1,200 feet above sea level. Along its tumultuous course, it has carved spectacular 800-foot-deep canyons.

If we could have continued eastward another eighteen miles, we would have reached Fundy National Park, but no road traversed the wild countryside. We retraced our route to Saint Martins to spend the night, and the next day followed an inland arc of highway that led over the Caledonia Highlands to the park. Cloaked with conifers, the highlands stretch from the Saint Johns River on the west to the Petit River to the east. Geologists consider the highlands to be an isolated outlier of the Appalachian chain.

Descending into lowland forest, we entered Fundy National Park from the inland side and, after about five miles, came to a parking area for the Caribou Plain Trail. After hiking a short distance on this two-mile-long path, we reached a boardwalk that crossed a twenty-acre beaver lake. The trail then passed

John Sylvester; First Light

The Bay of Fundy near Saint Martins



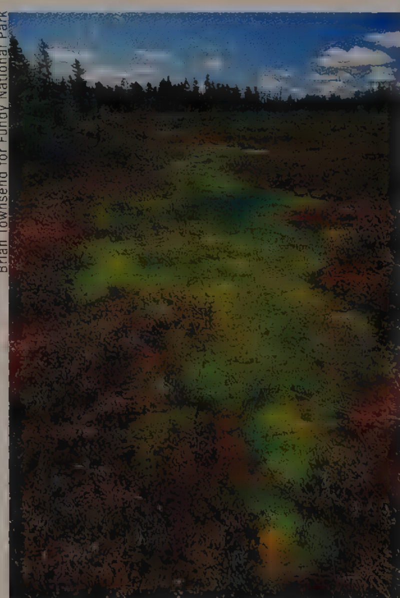
Brian Townsend

Sea milkwort, a coastal plant

[illegible] reminiscent of forests in Nova Scotia, occupies lower elevations bordering the Bay of Fundy. Red spruce and balsam fir are interspersed with red maple, quaking aspen, American beech, sugar maple, yellow birch, and other broad-leaved trees. Hobblebush viburnum and red osier dogwood dominate the shrub layer, while on the forest floor are scattered plants of bluebead lily, Canada mayflower, mountain sorrel, wild sarsaparilla, and large-leaved aster. Moist areas harbor long beach fern, woodland horsetail, white turtlehead, snowberry, and starflower.

[illegible] plants must withstand the rush of spring water and the scouring of melting ice. Quite a few have the requisite resilience, including a wild rose, a blue iris, bush honeysuckle, pink St.-John's-wort, and even a fragile-looking bedstraw.

[illegible] vegetation is dominated by spruces, firs, and pines. These conifers flourish in the thick soil of the ridge tops. On steep slopes, where less soil can accumulate, the rocky surface discourages the growth of conifers, but certain deciduous trees, such as striped maple and yellow birch, do fairly well.



Brian Townsend for Fundy National Park

A bog in Fundy National Park

[illegible] sampled along the Fundy National Park Caribou Plain Trail include a beaver lake. The exposed trunks of trees that have fallen in the water provide ideal habitat for myriad wetland plants. Common species are calla lily, pink St.-John's-wort, beggar's-tick (which looks like a small aquatic sunflower), touch-me-not, and a good variety of grasses, sedges, and rushes.

A pocket bog contains, in addition to sphagnum moss, such plants as Labrador tea, leatherleaf, cotton sedge, dwarf cranberry, bog laurel, a species of pitcher plant, and one of dwarf rhododendron. Black spruces, typical of boreal bogs, are scattered about. Bog rosemary, Labrador tea, sheep laurel, bakeapple, crowberry, and two kinds of sundews are


Barrett and MacKay Photo

Sugar maples

through a rather damp forest, over a slight rise, and dropped into a pocket bog, a poorly drained depression suitable for the growth of sphagnum (more commonly known as peat moss). Farther on we came to a large, flat opening with a few scattered black spruces. This was a raised bog, with plants growing on top of nine feet of accumulated sphagnum. Here and there were "flarks," narrow rivulets of water where the bog was torn. (For more on flarks, see "This Land," April 1994.) Beyond the raised bog, the trail plunged back into forest, eventually circling back to its starting point.

After visiting Fundy National Park, we sought out the gypsum-rich area near the village of Albert Mines, twenty-five miles to the east. This white mineral was mined for a number of years until it became unprofitable to do so. At one place along a small stream, white cliffs rise nearly one hundred feet above the water. Harboring some of the rarest plants in New Brunswick, these cliffs are protected as an ecological reserve.

Botanist Rob Walker, recently retired from Fundy National Park, accompanied us and scrambled over the cliffs to show us a number of unusual plants. They are arctic species, widely distributed in New Brunswick up until the end of the Ice Age, 10,000 to 13,000 years ago. As temperatures rose, glaciers retreated, and forests developed, these plants generally vanished from the region and occupied more northerly zones. But because the crumbly gypsum cliffs discouraged the growth of trees, the habitat remained hospitable to these arctic plants.

Robert H. Mohlenbrock, professor emeritus of plant biology at Southern Illinois University, Carbondale, explores the biological and geological highlights of United States national forests and other parklands.


Freeman Patterson; Masterfile

Bunchberries

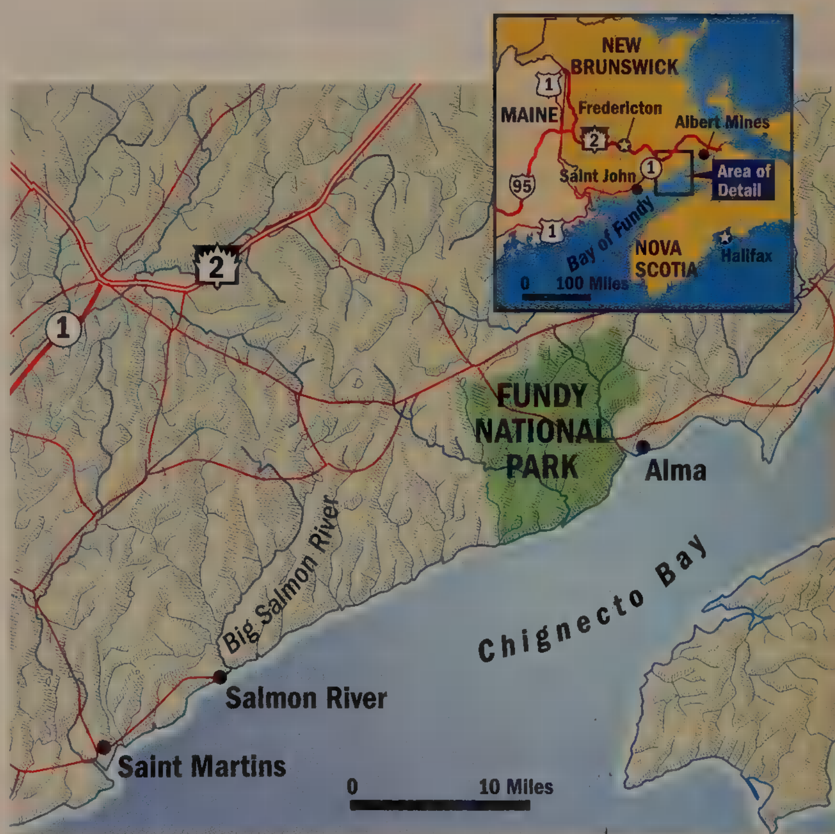
For visitor information write:
New Brunswick Department of Economic Development and Tourism
P.O. Box 6000
Centennial Building
Fredericton,
New Brunswick E3B 5H1
Canada
(506) 453-2964
or
Superintendent
Fundy National Park
P.O. Box 40
Alma,
New Brunswick E0A 1B0
Canada
(506) 887-6000

found in a raised bog. In the water of the flarks in the raised bog are yellow-flowered bladderworts, a tiny spikerush, white beakrush, and three-way sedge.


Tom Branch; Photo Researchers, Inc.

White Mountain avens

[redacted] have shallow pockets of soil supporting shrubby cinquefoil, narrow-leaved fleabane, harebell, alpine woods fern, and other common plants. Rarities for this maritime region include dwarf mountain goldenrod, White Mountain avens (a type of *Dryas*), and myrtle-leaved willow. The goldenrod, no more than a foot high, grows in only a few places in the Atlantic provinces. The avens is common in the Canadian Arctic, where it is a component of the tundra flora. The willow is found at one location in the Gaspé Peninsula of Quebec, as well as in northwestern Newfoundland, but its primary range is in northwestern North America.



Joe LeMonnier

Celestial Events

The Fairest Star

By Joe Rao

Sixty-four years ago, one of the brightest stars in the sky, Arcturus, was used to signal the start of the Chicago World's Fair. At the opening of the "Century of Progress" exposition, Arcturus's light was focused by telescopes onto photoelectric cells, and the current that was generated switched on the floodlights over the fairgrounds. Arcturus was chosen as the "inaugural" star because of its distance from Earth; by the best estimates of 1933, it would have taken the star's light forty years to reach Earth. Chicago had hosted the World's Fair in 1893—just forty years before. And so Arcturus generated publicity as well—newspapers around the country carried the story of how the 1933 fair would be opened by light that had started its journey to Earth while the 1893 fair was still in progress.

In May, Arcturus sparkles with a golden yellow hue, well above the eastern horizon. A huge star, it is about 25 times the diameter of the sun and possibly 100 times as luminous, but it is not nearly so hot or so dense. Locate it by means of the simple mnemonic "follow the arc to Arcturus." Follow the curve of the Big Dipper's handle, continuing in the same arc, about the length of the dipper itself and you will come to Arcturus.

Dennis Davidson

Follow the arc of the Big Dipper to find golden yellow Arcturus, the brightest star in the constellation Boötes.

Arcturus is the brightest star in the constellation Boötes, the Herdsman, who in early atlases was pictured as pursuing the Great Bear (Ursa Major) around the pole of the heavens. It may be easier to imagine the constellation as a large kite outlined by stars, with Arcturus at the point where the tail would be attached.

(A footnote to the story: today's more accurate measurements place the distance of Arcturus at 34 light-years.)

Joe Rao is a lecturer at the American Museum–Hayden Planetarium.

The Sky in May

Mercury's greatest western elongation—or distance from the Sun—occurs on the 22d, but the planet will be too low in the sky to be easily seen.

Venus is difficult to find for most of May. Early in the month, it is too close to the Sun to be seen, setting less than an hour after sunset. You might be able to spot it, to the lower right of a very young crescent Moon, right after sunset on the evening of the 7th. Otherwise, wait until the end of the month, when it can be more easily glimpsed low in the west–northwest just after sunset.

Mars is the only bright planet prominently placed in the evening sky. Look for it near the Leo-Virgo border. It is on the meridian as twilight ends, and it sets during the early morning hours. Mars continues to fade as Earth leaves it behind. On the 1st, it gleams at –0.5 magnitude, but by month's end, this golden orange world fades to +0.2, becoming dimmer than the similarly colored star Arcturus. A waxing gibbous Moon will be in the general vicinity of Mars on the evenings of the 15th and 16th.

Jupiter is in Capricornus rising after local midnight—about four hours before the Sun—and dominating the southeastern sky until dawn. Jupiter lies 4 degrees south of a waning gibbous Moon on the morning of the 28th.

Saturn, a yellow-white +0.8-magnitude "star" in Pisces, still lies low in the eastern morning twilight. It is close to the lower left of a waning crescent Moon on the morning of the 4th, and again (although not as close) on the morning of the 31st.

The Moon is at new phase on the 6th at 4:46 P.M., EDT. First quarter is on the 14th at 6:55 A.M., EDT; full Moon is on the 22d at 5:13 A.M., EDT; and last quarter is on the 29th at 3:51 A.M., EDT.

Comet Hale-Bopp makes its farewell appearance. This now-famous comet appears lower in the west–northwest sky each evening and sets about two and a half hours after the Sun on the 1st. On the 8th, the skinny sliver of a two-day-old Moon will sit 4 degrees below and left of the comet. This summer Hale-Bopp passes through the constellations of Orion, Monoceros, and Canis Major, fading as it sails back to deep space. It returns to our solar system about the year 4377.

Travel and Reading

Pollen Bees Among garden pollinators, bees are not as admired as butterflies or hummingbirds, but once you get to know them, they are just as fascinating. Most pollen bees are gentle, asserts Suzanne Batra, as long as you don't injure them; females can sting defensively. You can attract many species of pollen bees, she says, by growing a variety of flowering plants and providing nesting sites. Underground nesters, such as sweat bees, digger bees, and polyester bees, can be encouraged by leaving an undisturbed patch of sunny soil near your garden. If your yard is somewhat untidy, you may not have to entice bumblebees; they like wood piles, brush piles, and compost heaps—even old, discarded mattresses—and will appropriate abandoned field mouse nests in vacant lots.

Aboveground nesters make their own holes in a variety of materials. *Ceratina*—small, dark green bees that make good melon pollinators—seek out the dead stems of roses, grapes, sumacs, and brambles; encourage them by leaving dry trimmings of these pithy twigs about your garden. You may already unwillingly host carpenter bees. Large, fuzzy bees that like large flowers, they chew round holes wherever they find soft wood—including houses. If you construct a trellis with unpainted crossbeams of redwood or pine and plant wisteria to climb on it, these bees will love it. Mining bees, which are fast flying, fat, and fuzzy, dig their nests in cliffs and dry adobe walls in the central and southern United States. Attract mason bees (blue to greenish bees that are good pollinators of fruit trees) and leaf-cutters (black to grayish bees that favor clover and alfalfa) by drilling smooth-walled holes of various diameters and depths in a block of seasoned, dry, untreated wood (see illustration, left). Hang it in a sunny place, but where it will be protected from rain.

A wood-block nest may be used by leaf-cutter and mason bees.

A book with very good color photos is Christopher O'Toole and Anthony Raw's *Bees of the World* (Facts on File, 1992). A children's pop-up book, *The Bee,* by Beth B. Norden, is available from BioQuip, (310) 324-0620. A family board game called Nectar Collector can be ordered from Animal Town, P.O. Box 485, Healdsburg, CA 95448, (800) 445-8642.

Bonobo Dialogues
Bonobos live in isolated areas of Zaire inaccessible to tourists; you can see bonobos only in zoos fortunate enough to have them. As reported by Frans de Waal in his book *Bonobo: The Forgotten Ape,* only a hundred or so bonobos live in captivity, in groups ranging from two to eleven individuals per zoo; compare this with the thousands of chimpanzees living in colonies of as many as thirty. In the United States, bonobos are in the Milwaukee, San Diego, Cincinnati, Columbus, and Fort Worth zoos. Germany also has a scattering of bonobos in zoos in Frankfurt, Cologne, Berlin, Wuppertal, Leipzig, and Stuttgart. In Belgium, you'll find bonobos in the Mechelen and Antwerp zoos; in Great Britain at the Twycross Zoo; and in Mexico at the zoo in Morelia.

To observe social and sexual interactions, says Frans de Waal, the amateur ape watcher should stop by the zoo on a regular basis and learn to distinguish the resident bonobos by their faces and personalities.

Takayoshi Kano's account of bonobos in Zaire ("The Bonobos' Peaceable Kingdom") appeared in *Natural History* in November 1990, and his book *The Last Ape: Pigmy Chimpanzee Behavior and Ecology* was published by Stanford University Press in 1992.

Where Life Springs Ephemeral
To observe amphibians and other creatures in a vernal pool, says Mark DesMeules, your best bet is to arrange for a local guide to take you to one or sign up for a field trip. For information, contact an Audubon Society chapter, Nature Conservancy office, or your state's Natural Heritage Program (generally housed in the Fish and Wildlife office of the Environmental Conservation Department). The best time for a vernal pool visit varies from one region to another; in the northeast, it's from late March through April. Ideally, says DesMeules, you should wait for a good, strong rain that begins in early afternoon and continues through the night. Be sure to bring along hip waders, reliable rain gear, a headlamp, and at least one waterproof flashlight. A laminated pocket guide, *Pond Watchers: A Guide to Ponds and Vernal Pools of Eastern North America,* is published by the Massachusetts Audubon Society (617) 259-8805.

Edited by Jeanne Flagg

All photographs by Robb Walsh

Young and mature (red) seed pods from a Hawaiian cacao tree

The Cho

By Robb Walsh

Jim Walsh, on his knees in a pile of rotting vegetation, is admiring a big, red fruit pod that protrudes from the trunk of a very healthy-looking cacao tree. Walsh (who is no relation to me) is the father of the fledgling Hawaiian chocolate industry, and he is very fond of this particular cacao plantation high in the mountains above the Kona coast of the Big Island of Hawaii.

The ten- to fifteen-foot-high cacao trees look like shrubs beside the towering macadamia nut trees in the adjacent orchard. The Hodge's Estate, as this plantation is known, used to grow only coffee and macadamia nuts. Now it also produces Walsh's most prized chocolate. Walsh's Hawaiian Vintage Chocolate Company sells chocolate by estate and year of vintage, like fine wine.

A light rain is falling and I can't help thinking that the place looks a mess—I am standing ankle-deep in a pile of wet, decaying organic debris.

"Do cacao trees need this much mulch?" I ask diplomatically, after slipping on a pile of wet cacao leaves.

"No, but the midges love it," Walsh replies as he twists a fruit pod off the tree.

"Midges?" The connection between no-see-ums, the tiny flies that bite exposed human flesh on sandy beaches, and chocolate is completely lost on me.

"If there weren't any midges, there

After seeds are fermented in a vat, a worker spreads them on screens to dry in the sun.

colate Bug

Its beans are valued all over the world, but the cacao tree grows in very few places. The plant's survival depends on a tiny insect that is finicky about where it lives.

Specimen, Allen Young; Milwaukee Public Museum

SEM, R. Shammani; AMNH

An electromicrograph (×17) of the midge Forcipomyia fuliginosa

wouldn't be any chocolate," says Walsh with an enigmatic grin, tossing me the red cacao pod, which resembles a partly deflated football.

The cacao tree bears fruit that is also called cacao (pronounced ka-KOW). The seeds inside the fruit pods are the cacao beans from which chocolate is made. Midges, as it turns out, are the only known pollinators of cultivated cacao. And a dearth of midges is one of the biggest problems facing the world's chocolate producers.

"There are cacao plantations in Central America that get only 400 pounds of fruit per acre compared to the 4,000 to 6,000 pounds an acre we get here in Hawaii," says Walsh. "All because they don't have as many midges as we do."

Jim Walsh takes back his shrunken football and breaks the cacao fruit in half. Inside, there is a loose sac of sticky, transparent fruit enclosing thirty or forty thick, black seeds. Walsh encourages me to eat a little of the gooey fruit. Although it has a faint aroma of chocolate, the mucilaginous cacao flesh actually tastes more like lemon Jell-O. Walsh eats a little bit of it himself.

"It tastes good, doesn't it? We're thinking of making it into some kind of soft drink," says Walsh. He tells me that cacao fruit has been used to make beverages in Latin America for centuries.

When cacao was first harvested by South American Indians thousands of years ago, the sweet, citrusy mucilage was what interested them. Their interest was shared by bats, rats, squirrels, and monkeys, which gnawed through the skin of the cacao fruit to eat the pulp. Both humans and animals discarded the bitter-tasting cacao beans, thus guaranteeing the tree's dispersal. Cacao fruit pods are cauliflorous; that is, they grow out of the tree's trunk and branches rather than from the branch tips. And no matter how ripe they become, they never fall from the tree, which means that cacao is completely dependent on animals to spread and propagate it.

The tropical humidity of the Amazon Basin will cause cacao beans to rot if they are left out in the sun. So the seductive flavor of chocolate was not fully appreciated until cacao was cultivated in the drier climates of Central America and Mexico, where the cacao beans could be easily dried. Just how cacao came to Central America and how the uses of the bean were first discovered is, alas, unknown.

We do know that in ancient Mesoamerica, chocolate culture reached its full flower. Chocolate was not only a luxurious beverage but also a sacramental drink and a form of currency. Powdery residues taken from ancient Mayan stirrup-handled jars unearthed by archeologists were found to contain cacao. The English (and Spanish) word *chocolate* comes from *chocolatl,* the name of an Aztec beverage made of cacao, chiles, and vanilla beans. There was plenty of gold and silver in preconquest Mexico, but neither was used as money. Aztec traders paid their debts in cacao beans.

The drier climates of Mesoamerica made chocolate production practical and cacao beans valuable to the Maya and Aztecs, but it also made growing cacao fruit more difficult. The insects that pollinate cacao are scarce in dry environments. This is the paradox that still plagues chocolate producers the world over.

Soon after Jim Walsh started his chocolate operations in Hawaii, he was visited by a midge specialist. "Chocolate had never been grown commercially in Hawaii, and we had no idea if we had the right kinds of midges here," Walsh says. The man who came to investigate was Allen M. Young, curator of zoology at the Milwaukee Public Museum and the author of a comprehensive book on cacao, *The Chocolate Tree* (Smithsonian, 1994). Young has been studying insects of the tropical rain forest since 1968 and their relation to chocolate production since 1979. He was curious to see for himself whether the right pollinating insects for cacao would be found in Hawaii.

Young inspected several test plantings of cacao in the islands. He checked the leaf litter around the trees for midge larvae and observed the flowers on the trees

for midge activity. Potential plantation sites were judged for their attractiveness to midges. "Western Maui was too dry," Young remembers. "The sites I visited on the Big Island of Hawaii were much better for the midges."

Technically, the pollinators of cacao are dipteran flies of the family Ceratopogonidae, also known as biting midges. Young describes midges as "specks of dust on wings." The problems of fieldwork and taxonomy are difficult enough without having the dust specks biting you. However, the various species that pollinate cacao don't really bite.

"Midges have no ecological dependency on cacao," Young explains. "Their lack of fidelity means they are probably generalist pollinators." Young has done most of his cacao pollination studies in Costa Rica, where the pollination rate is less than 5 percent. But the problem is not unique to Costa Rica. "Everywhere cacao is cultivated, the trees set very few fruits in relation to the large number of flowers they bear."

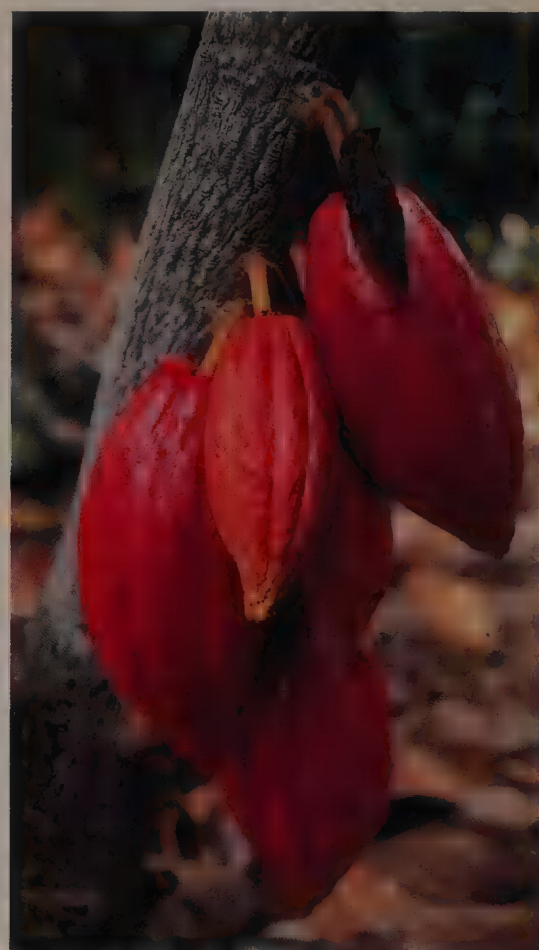
Cacao is not unique in its pollination problems. Its sister flavoring, vanilla, presents an even tougher challenge to farmers. In its native region in Mexico, vanilla—which is actually a fruiting orchid—is pollinated by orchid bees. In Madagascar, where much of the world's commercial vanilla is now grown, there aren't any orchid bees, and pollination must be done by hand with tiny paint brushes.

In the same area of northeastern Costa Rica where Allen Young did his field experiments with cacao, a local spice farmer unsuccessfully attempted to grow vanilla from Mexican cuttings. Young remembers touring the vanilla orchard one day, looking at the shriveling flowers and wondering why the local orchid bees were ignoring them.

"In the middle of this field of cultivated vanilla plants, I came across a wild vanilla plant that had somehow taken root," says Young. "The cultivated vanilla plants were bare, but the wild plant was heavy with fruit. The local orchid bees evidently recognized the color and shape of the wild vanilla flowers, but not those of the cultivated variety. What a lesson in pollination that was!"

Young has always wondered whether an insect in the Amazon Basin has the same sort of relationship with cacao that those orchid bees had with the local wild vanilla. In Costa Rica, he has tried introducing various species of bees into cacao plantations, but none showed any interest in the cacao flowers. With no other pollinator available, Young turned his attention back to the midges.

One of the major problems with cacao



First cultivated in Central America, the cacao tree originated in South American rain forests.

pollination is that the midge population reaches its height toward the end of the rainy season, whereas cacao begins to flower at the beginning of the rains. Checking various field sites for midge larvae during the peak flowering period, Young noticed a high concentration of midge larvae in the rotting remains of cut-down banana plants.

So he conducted experiments in which banana stem cuttings were strewn among the cacao plants. "We pushed up pollination by as much as 15 percent by bringing in the banana stem litter," Young told me. Suddenly, Jim Walsh's penchant for messy cacao plantations made a lot more sense.

But he wasn't really satisfied with the organic litter solution. The experiment also led him to question the basic premise of the plantation system. Planting cacao in neat rows with clean open spaces between them may be convenient for humans, but it's not very appealing to midges. And while the banana stem litter might mitigate the problem, Young wondered what would happen if cacao were planted in a tropical rain forest environment to begin with.

So he conceived an experiment that is now being conducted in Costa Rica. The Milwaukee Public Museum, together with the Riveredge Nature Center, has purchased 740 acres of rain forest that will be used as a field research site and for public education programs. A managed rain forest experiment will allow valuable timber to be removed from the rain forest while damage is kept to a minimum. In the spaces created by removing the timber, small cacao groves will be planted. The pollination rate and cacao fruit yield will be measured against three other experimental plots, one in a secondary forest, one in an old pasture, and one in a conventional plantation under a shade canopy of rubber trees. Young hopes to test his hypothesis that pollination can be improved by returning the plant to an environment that closely resembles its natural habitat.

If managed rain forests turn out to be more economical places to grow cacao than old-fashioned plantations on cleared land, then environmentalists and chocolate lovers alike should fall down on their knees (but, hopefully, not in the leaf litter) and thank the accommodating midges.

Culinary adventurer Robb Walsh received the 1996 James Beard journalism award for his writings about food.

(Continued from page 21)

Codex Leicester, and occupies several full pages of text—one, for example, entitled "Of the Flood and of marine shells," and another, "Refutation of such as say that the shells were carried a distance of many days' journey from the sea by reason of the Deluge."

Second, Leonardo dismisses, even more contemptuously, various Neoplatonic versions of the theory that fossils are not remains of ancient organisms at all, but rather manifestations of some plastic force within rocks, or some emanation from the stars, capable of precisely mimicking a living creature in order to illustrate the symbolic harmony among realms of nature: animal, vegetable, and mineral. If fossils really belong to the mineral kingdom, then their position on the tops of mountains ceases to be anomalous, as we need no longer believe that these objects ever inhabited the seas.

Leonardo made observations 7 to 9 to refute this Neoplatonic theory that fossils "grew" within their entombing rocks and do not represent the remains of organisms. If marine fossils are inorganic, why don't they "grow" in all strata, rather than only in rocks carrying abundant evidence of an oceanic origin (observation 7). If fossils belong to the mineral kingdom, why should they so often grow in fragments and jumbles looking exactly like piles of shells on our beaches, or layers deposited by rivers in lakes and ponds (observation 8). Most convincingly, if fossils grow from inorganic "seeds" in the rocks, how can they expand, year by year, as indicated by growth bands in their shells, without fracturing the surrounding matrix (observation 9).

Leonardo reserved his choicest invective for what he regarded as the lingering magical content of this Neoplatonic theory of signs and signatures (although the issue remained alive—and quite lively—within Western science until the late seventeenth century. The *Mundus subterraneus* (1664) of the great Jesuit scholar Athanasius Kircher represents the last seriously cogent defense of the Neoplatonic position). Leonardo writes:

> *And if you should say that these shells have been and still constantly are being created in such places as these by the nature of the locality and through the potency of the heavens in those spots, such an opinion cannot exist in brains possessed of any extensive powers of reasoning because the years of their growth are numbered upon the outer coverings of their shells [observation 9 again]; and both small and large ones may be seen, and these would not have grown without feeding or feed without movement, and here [that is, in solid rock] they would not be able to move. . . . Ignoramuses maintain that nature or the heavens have created [fossils] in these places through celestial influences.*

But demonstrating that Leonardo made his paleontological observations to refute the prevailing theories of his time scarcely establishes my argument that he must be evaluated as a thinker immersed in his own premodern context and not judged for his remarkable foreshadowing of twentieth-century views—for a true spaceman would also have to refute the fallacies of his surroundings in order to introduce superior views from his time warp (just as Hank Morgan had to reject the running messenger service in favor of a telephone call for summoning Sir Lancelot's bicycle corps). I must advance a further claim—one that can be particularly well documented in Leonardo's case.

Just as Leonardo made his astute observations to refute prevailing theories of fossils, he also urged his interpretations in support of his own favored theory of the earth. ("All observation must be *for or against* some view"). And the positive prod for Leonardo's paleontological observations could not have been more squarely Renaissance or late medieval, more firmly attached to his own time and concerns—and not to ours. Leonardo observed fossils as part of his quest to support a distinctive theory of the earth—a framework that would be seriously weakened if either Noah's flood or the Neoplatonic theory of fossils were true. If Leonardo had not been so devoted to his "antiquated" theory of the earth, I doubt that he would ever have been inspired to make his wonderfully "modernist" observations about fossils—for the notebooks invariably present his observations as arguments to support his theory.

Leonardo loomed so much larger than life, even in the eyes of his contemporaries, that a potent mythology began to envelop him right from the start. Only thirty years after Leonardo's death, Giorgio Vasari published a first biography full of such touching tall tales as Leonardo's death in the arms of King Francis I. (Francis did admire Leonardo greatly, but he and his entire court had decamped to another town on the day of Leonardo's demise. (A. Richard Turner has written an entire, and fascinating, book on the history of the Leonardo legend through the ages—*Inventing Leonardo,* University of California Press, 1994.) One prominent component of the myth—that Leonardo was an unlettered man who could only work by observation and therefore gained great (if ironic) benefit from *not knowing* the false traditions of medieval Scholasticism—must be refuted if my case for his medieval impetus has merit. For how could I assert such a controlling context if Leonardo never knew or studied the prevailing traditions of printed scholarship in his time?

As the illegitimate son of a Florentine notary, Leonardo grew up in reasonably comfortable but nonscholarly circles and received only a limited formal education. Most importantly, he did not learn Latin, then the nearly universal language of intellectual communication. But Leonardo did study Latin assiduously in later life, even if he never attained more than a halting knowledge. (I love Martin Kemp's statement in his superb book *Leonardo da Vinci: The Marvelous Works of Nature and Man*: "It is rather humbling to think of Leonardo in his late thirties secretly

schooling himself in the rhythmic rotes of *'amo, amas, amat . . .'*, like one of the children of the court.")

Moreover, Leonardo studied Latin because he yearned to gain full access to the scholarship of classical and medieval sources. He built a respectable library for the time—Italian translations whenever possible, but original Latin sources when necessary. He read particularly widely and deeply in this essay's subject of paleontology and the structure of the earth. Kemp writes: "He was taking up questions which had provided considerable bones of contention in classical and medieval science. An impressive roll-call of classical authorities contributed to his education in physical geography. . . . There probably is no other field in which Leonardo's knowledge of classical and medieval sources was so extensive."

He read the Greek masters Aristotle and Theophrastus on geology; he owned a copy of Pliny's encyclopedic *Natural History;* he studied the views of the great Islamic scholars Avicenna and Averroës (mainly via medieval Christian sources). He listed parts of what he had read and owned on the inside front cover of his *Manuscript F*: Aristotle's *Meteorologia,* Archimedes on the center of gravity, "Albertuccio and Albertus *de coelo et mundo.*" (The last comment is particularly sweet, as Leonardo follows medieval conventions in distinguishing his sources as "Little Al" [the Italian diminutive Albertuccio] and "Big Al." Little Al is Albert of Saxony [ca. 1316–1390], the German Scholastic philosopher and physicist. Later scholars frequently confused him with Big Al, or Albertus Magnus [ca. 1200–1280], Albert the Great, the teacher of Thomas Aquinas. Both Als wrote extensively about the form and behavior of the earth, and Leonardo probably learned the views of Jean Buridan [1300–1358] by reading Albert of Saxony's discussion. Buridan's views became the basis of the theory of the earth that Leonardo defended with his observations on fossils.)

What theory of the earth, then, did Leonardo seek to support with paleonto-

logical data? Simply stated, Leonardo was vigorously promoting a common and distinctively premodern view that could not have been more central to all his thought and art: the comparison, and causal union, of the earth as a macrocosm with the human body as a microcosm. We tend to regard such comparisons today as "merely" analogical or "purely" metaphorical—more apt to promote a deluding sense of false unity than any genuine insight into common causality. Leonardo's premodern world viewed such consonances as deeply meaningful, in part by invoking the same general theory of symbolic correspondence across scales of size and realms of matter that Leonardo (ironically) had rejected so vigorously in denying the Neoplatonic idea that fossils might grow within rocks as products of the mineral kingdom.

No theme recurs so incessantly, and with such central import, both in the *Codex Leicester* and throughout Leonardo's writing, as the causal and material unity of the body's microcosm and the earth's macrocosm. Leonardo also knew the ancient pedigree of this doctrine, from classical antiquity through medieval Scholasticism. In the *A Manuscript* (now in the Institut de France), Leonardo stated that he would begin his "Treatise on Water" (never completed or published) with a statement that he later repeats almost verbatim in the *Codex Leicester:*

> *Man has been called by the ancients a lesser world, and indeed the term is rightly applied, seeing that if man is compounded of earth, water, air and fire, this body of the earth is the same; and as man has within himself bones as a stay and framework of the flesh, so the world has the rocks which are the supports of the earth; as man has within him a pool of blood wherein the lungs as he breathes expand and contract, so the body of the earth has its ocean, which also rises and falls every six hours with the breathing of the world [the tides]; as from the said pool of blood proceed the veins which spread their branches through the human body, in just the same manner the ocean fills the body of the earth with an infinite number of veins of water.*

A close look at the background and details of the *Mona Lisa* affirms the centrality of the same analogy in Leonardo's art, as many scholars have noted, and as Martin Kemp describes particularly well. La Gioconda stands on a balcony overlooking a complex geological background of flowing waters that complete a full hydrological cycle just as blood moves through the human body. Kemp notes:

> *The processes of living nature are not only mirrored by anatomical implication within the lady's body, but are more obviously echoed in the surface details of her figure and garments, which are animated by myriad motions of ripple and flow. The delicate cascades of her hair beautifully correspond to the movement of water, as Leonardo himself was delighted to observe: "Note the motion of the surface of the water which conforms to that of the hair." . . . The little rivulets of drapery falling from her gathered neckline underscore this analogy, as do the spiral folds of the veil across her left breast.*

We now reach the central dilemma and resolution that make the paleontological observations so crucial to the argument of the *Codex Leicester.* This notebook, as scholars have always recognized, is primarily a treatise on the nature of water in all its properties, manifestations, and uses. So why does Leonardo devote so much apparently subsidiary space to the nature of fossils and the reason for their situation in mountain strata, far above present sea level? The key to this problem lies in Leonardo's almost heroic struggle to overcome a central difficulty in validating his crucial analogy of the body's microcosm to the earth's macrocosm. Most scholars have missed this theme and therefore do not grasp the union of the hydrological and paleontological passages of the *Codex Leicester.*

Leonardo recognizes only too well—for he has struggled with this problem for

years and through several notebooks—that his crucial analogy suffers from a potentially fatal difference between the human body and the earth. Both are built of the four elements of antiquity: earth, water, air, and fire. But the human body sustains itself by circulating these elements, particularly by maintaining some mechanism for permitting water (blood) to rise from the legs to the head. The analogy of microcosm and macrocosm can only work if the earth also possesses a comparable mechanism for sustenance by cycling of elements.

But how can such a notion be defended for the planet, especially in the light of the following problem: earth and water are heavy elements; their natural motion can only be down (leading ideally to a planet of four concentric layers with earth at the center, water above, air atop water, and fire at the periphery). But if earth and water can only move down, they must come to rest in two concentric spheres at the center of the planet—and the macrocosm will therefore possess no device for sustenance by circulation. Leonardo knows that he must therefore find a mechanism that will make both earth and water *move up,* as well as down, on our planet. This pressing need, so difficult to validate, sets the central struggle that Leonardo exposes to our view throughout the *Codex Leicester.*

Ironically, I wish to argue, he never did solve the problem for his main subject of the codex—water. That is, he tried again and again, but never found a satisfactory mechanism to guarantee the upward motion, hence the cycling, of water. However—and this is the vital point that has usually been missed—Leonardo did succeed (according to his lights) in his quest to find a mechanism for upward movement of the other heavy element: earth. Fossils on mountains provide the observational proof that earth can rise, both generally and often. For marine shells once inhabited the sea but now reside in the high mountains. The paleontological observations received such prominence in the *Codex Leicester* not, as has usually been argued, because fossils once lived in water and the codex treats water in all major aspects (an awfully lame reason for devoting so much space to paleontology) but rather because fossils mark Leonardo's great success (in contrast to his failure for the central subject of water) in illustrating a general mechanism for the upward motion of earth, and therefore for a self-sustaining planet that may legitimately be compared with the human body.

Leonardo knew only too well that he faced a serious problem with the motion of water through the earth, and he virtually obsesses over the issue in notebook after notebook, repeating the conundrum in almost unchanging words and proposing various solutions, only to abandon them later as untenable. Water, by itself and following its "natural course" (Leonardo's words) can only flow down. But within the body of the earth, water also moves up to emerge as springs near the tops of high mountains (and thence back on track, to flow as rivers to the sea). An earthly force must therefore make water rise through the land against its natural inclination to flow down. The combined action of these two forces will cause water to circulate—and thereby act like the blood in our bodies to sustain a living system:

> *So does the water which is moved from the deep sea up to the summits of the mountains, and through the burst veins [mountain springs] it falls down again to the shallows of the sea, and so rises again to the height where it burst through, and then returns in the same descent. Thus proceeding alternately upwards and downwards at times it obeys its own desire [to move down] at times that of the body in which it is pent [to move up].* (From the *Arundal Codex* in the British Museum).

Leonardo could not have been more explicit in admitting that water can move up only by running against its natural course and that, if some mechanism can

be found at all for this anomalous motion, the analogy between microcosm and macrocosm offers the only reasonable hope for a solution:

> *Clearly it would seem that the whole surface of the oceans, when not affected by the tempest, is equally distant from the center of the earth, and that the tops of the mountains are as much farther removed from this center as they rise above the surface of the sea. Unless therefore the body of the earth resembled that of man, it would not be possible that the water of the sea, being so much lower than the mountains, should have power in its nature to rise to the summit of the mountains. We must therefore believe that the same cause that keeps the blood at the top of a man's head keeps water at the summit of the mountains.* (From the *A Manuscript* in the Institut de France.)

But to state a need is not to find a mechanism. Throughout the *Codex Leicester,* Leonardo struggles to discover a physically workable way to raise water within the earth. He tries and rejects several explanations, as Martin Kemp documents in "The Body of the Earth," an article written for the catalog to the recent display of the *Codex Leicester.* Perhaps, Leonardo first argues, the heat of the sun draws water up through the veins (internal streams) that run through mountains. (Leonardo, in his strongest image of a living earth, had written in the *Codex Leicester:* "The body of the earth, like the bodies of animals, is interwoven with a network of veins, which are all joined together, and formed for the nutrition and vivification of the earth and of its creatures.") But he then decides that this explanation cannot work for two reasons—first, because, on the highest mountaintops closest to the heating sun, water remains cold and even icy; and, second, because this mechanism should operate best in summer during maximal solar heat, but mountain streams often flow with lowest output at this time.

In a second try, Leonardo turns to the earth's internal heat and a process of distillation: perhaps the interior fires boil water in internal caverns, and this water rises as vapor through mountain interiors, where it reverts to liquid form and bursts through as a high spring. But this proposal won't work either because such extensive distillation would require that the roofs of internal caverns be wet with the rising steam—but they are often bone dry. Leonardo then made a feebler third attempt: perhaps, by analogy to a sponge, mountains somehow suck up water to a point of saturation and subsequent oozing from the top. But Leonardo realizes that he cannot cash out this analogy in mechanical terms:

> *If you should say that the earth's action is like that of a sponge which, when part of it is placed in water, sucks up the water so that it passes up to the top of the sponge, the answer is that even if the water itself rises to the top of the sponge, it cannot then pour away any part of itself down from this top, unless it is squeezed by something else, whereas with the summits of the mountains one sees it is just the opposite, for there the water always flows away of its own accord without being squeezed by anything.*

But if Leonardo, to his great disappointment, never solved the problem of rising waters, he did (to his satisfaction) crack the equally knotty problem of a general mechanism for the elevation of earth—a combination of his views on gravity and his concept of erosion. (I struggled with Leonardo's complex mix of idea for many days—a mélange of Scholastic theories of gravity and the earth, mainly vouchsafed to Leonardo by Jean Buridan through the books of Albert of Saxony, and of Leonardo's conjectures on composition of the earth's interior combined with observations on our planet's surface—but I am now confident that I grasp the argument and can present a crisp epitome.)

Our planet has a geometric center, called by Leonardo the "center of the world"—or sometimes the "center of the universe," for Leonardo accepts the Ptolemaic system of a central earth and a revolving sun. The realm of liquid water must arrange itself as a perfect sphere about this center, with the surface of the ocean equidistant at all points from the center of the world. If the solid earth were homogeneous and equally distributed, it would also form a smooth sphere with a surface equidistant at all points from the center of the world.

But the heavy earth is far from homogeneous. The interior of our planet is a complexly marbled mass of solid earth, liquid water running through veins in the rocks, and even air, where water has hollowed out caverns in the rocks. Therefore, as a result of this unequal distribution of earth, one hemisphere will always be heavier than the other.

Now, the planet also has a center of mass (called by Leonardo, in a terminology that we would not use today, a "center of gravity"). On a homogeneous planet, this center of gravity will coincide with the geometric center of the world. But on our actual planet, with one hemisphere heavier than the other, the "center of gravity" will lie *below* the geometric center and within the heavier hemisphere. Yet the planet must strive, as a living body seeking balance, to bring the center of gravity closer to the geometric center. The earth pursues this goal in a manner known from time immemorial to all riders on seesaws (the *Codex Leicester* contains a picture of such a seesaw, albeit for a different purpose). To balance a seesaw, the heavier person must move toward the fulcrum at the center, while the lighter person must move away. In exactly the same manner, the solid masses of the heavier hemisphere must sink toward the center of the world, while the rocks of the lighter hemisphere must rise. The emergence of mountains from the seas, and the consequent placement of marine fossils on high hills, records this rising of land in the earth's lighter hemisphere.

Leonardo succinctly describes the gen-

eral process in *Manuscript F* (in the Institut de France):

> *Because the center of the natural gravity of the earth ought to be in the center of the world, the earth is always growing lighter in some part, and the part that becomes lighter pushes upwards, and submerges as much of the opposite part as is necessary for it to join the center of its aforesaid gravity to the center of the world; and the sphere of the water keeps its surface steadily equidistant from the center of the world.*

Leonardo must then find a general mechanism for lightening one hemisphere, while making the other heavier—and he succeeds with two principles, both based on erosion by water: one mode operating in the earth's interior, the other at

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Leonardo's mechanism for the rising of mountains: the upper hemisphere becomes lighter when a large mass of earth falls to the center of the planet.

the earth's surface. In the interior, internal veins of water carve out caverns, which eventually become unstable. Their tops finally collapse, and enormous blocks of rock fall all the way to the center of the world. There, the blocks distribute themselves about the center with approximately equal volume in each hemisphere—thus adding weight to one

hemisphere and subtracting from the other (for the entire block had previously resided in one hemisphere alone). Leonardo includes a striking illustration of this process in the *Codex Leicester,* showing a fallen block as a large arch nicely draped about the center of the world. In describing this internal mechanism in the *Codex Leicester,* Leonardo explicitly cites the rising of fossiliferous strata as a consequence:

> *The fact of the summits of the mountains projecting so far above the watery sphere may be due to the fact that a very large space of the earth which was filled with water, that is the immense cavern, must have fallen in a considerable distance from its vault toward the center of the world, finding itself pierced by the course of the springs, which continually wear away the spot through which they pass. . . . Now this great mass has the power of falling. . . . It balances itself with equal opposing weights round the center of the world, and lightens the earth from which it is divided; and it [the lightened earth] removed itself immediately from the center of the world and rose to the height, for so one sees the layers of the rocks [with their fossils], formed by the changes which the water has undergone, at the summits of the high mountains.*

The exterior method of lightening by erosion can enhance this process once the mountains rise. Rivers will now erode the sides of the mountains and carry sediment away to the oceans. Some sediment will flow to the opposite hemisphere, thus further increasing the imbalance of weight, and causing the mountains to rise still higher as a consequence.

> *And now these beds are of so great a height that they have become hills or lofty mountains, and the rivers which wear away the sides of these mountains lay bare the strata of the shells, and so the light surface of the earth is continually raised, and the antipodes [the opposite side of the earth] draw nearer to the center of the earth, and the ancient beds of the sea become chains of mountains.*

Thus, and finally, we grasp the central importance of Leonardo's paleontological observations in the *Codex Leicester.* He featured this subject in order to validate the most cherished centerpiece of his premodern worldview—the venerable argument, urged throughout classical and medieval times, for considering the earth as a living, self-sustaining "organism," a macrocosm working by the same principles and mechanisms as the microcosm of the human body. Leonardo required, above all, a general device to make the heavy elements, earth and water, move upward against their natural inclination—so that the earth could sustain itself, like a living body, by constantly cycling all its elements, rather than reaching inert stability with heavy elements in permanent layers below lighter elements.

Leonardo failed to find such a mechanism for the chief subject of the *Codex Leicester:* water—and this lack of resolution caused him great frustration. But he succeeded for the even heavier element of earth. He extended a mechanism proposed by Scholastic philosophers for causing the lighter hemisphere of an unhomogeneous planet to rise. He proposed both internal and external erosion by water as devices that could lighten a hemisphere—but he needed observational evidence that land did, in fact, rise. His crowning jewel of confirmation lay in a well-known phenomenon that had provoked intense debate ever since the days of classical Greek science—fossils of marine organisms in strata on high mountains.

Leonardo also needed to assert that the rising of strata with fossils must represent a general and repeatable feature of the earth's behavior, not an odd or anomalous event. Thus, he had to refute the two explanations for fossils most common in his time—for Noah's flood could only be viewed as a strange and singular phenomenon, and if all fossils derive from this event, then paleontology illustrates no general mechanism for the rising of land. And if fossils grow as objects of the mineral kingdom within rocks, then the mountains may always have stood high, and we can derive no evidence for any uplift at all. Thus, Leonardo made his superb observations on fossils to validate his lovely, but ever so antiquated, view of a causally meaningful and precise unity between the human body as a microcosm and the earth as a macrocosm. Leonardo, the truly brilliant observer, was no spaceman, but a citizen of his own instructive and fascinating time.

I like to contemplate Leonardo, this complex man of peace, of gentleness, of art, of scholarship; this military engineer who designed (but generally did not build) ingenious instruments of war, but who would not reveal his ideas for a submarine, as stated in the *Codex Leicester:*

> *This I do not publish or divulge on account of the evil nature of men who would practice assassinations at the bottom of the seas, by breaking the ships in their lowest parts and sinking them together with the crews who are in them.*

And I like to compare his views on the mechanism for raising mountains from the sea (and exposing fossils for collectors) with our most celebrated literary image on the same subject—Isaiah's prophesy that "every valley shall be exalted." I also recall the peace that shall reign on Isaiah's mountain (festooned, no doubt, with fossils), where a scholar might study the raising of earth to his heart's content and not need to provide his warlike patron with plans for the raising of sieges or the razing of enemy cities—Isaiah's summit, where "the wolf also shall dwell with the lamb, and the leopard shall lie down with the kid. . . . They shall not hurt nor destroy in all my holy mountain."

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sufficient to shred a star before it crosses the event horizon. When this happens, all of the star's gravitational potential energy is converted into speed (like that of the freshly baked pie as it fell out of the window but before it hit the ground) and the stars are eaten whole as they plunge through the event horizon. No more conversion to heat and radiation. This shut-off valve kicks in for a black hole when it becomes about a billion times the mass of the Sun.

The unified picture would account for a scenario in which quasars and other active galaxies are just early chapters in the life of ordinary galaxy nuclei. If this is true, specially exposed images of quasars should reveal the surrounding fuzz of a host galaxy. The observational challenge is similar to that faced by planet hunters who try to detect planets hidden in the glare of a host star. The quasar is so much brighter than the surrounding galaxy that masking techniques must be used to detect anything other than the quasar. Sure enough, nearly all high-resolution images of quasars have revealed surrounding galaxy fuzz. The several exceptions—uncloaked quasars—continue to confound expectations based on the standard model. Or are the host galaxies simply too faint to be detected? The data remain controversial.

The unified picture also accounts for quasars eventually shutting themselves off. Actually, the absence of nearby quasars

requires this. But it also means that black holes in galactic nuclei should be common, whether or not the galaxy has an active nucleus. Indeed, the list of nearby galaxies with dormant supermassive black holes in their nuclei has grown to two dozen—and includes the Milky Way. The smoking gun in each galaxy is the unexpectedly astronomical speed that stars achieve as they orbit close (but not too close) to the central black hole.

Such scientific models are always seductive, but one should occasionally ask whether the model actually captures some deep truths about the universe, or whether it was constructed with so many tunable variables that you can use it to explain anything at all. Similarly, have we been sufficiently clever today, or are we missing a tool that will be invented or discovered tomorrow? The English physicist Dennis Sciama, of the University of Oxford, was asking himself a similar question when he penned:

> *Since we find it difficult to make a suitable model of a certain type, Nature must find it difficult too. This argument neglects the possibility that Nature may be cleverer than we are. It even neglects the possibility that we may be cleverer tomorrow than we are today.*

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The Young and the Nestless

Photograph by Derrick Hamrick

On a mid-April morning in Wake County, North Carolina, photographer Derrick Hamrick, hidden in his blind, saw the wood duck hen peering right and left for ten minutes from the edge of the nest cavity. He knew his long wait was over. The hen, sensing no danger, flew to the marshy ground and uttered a call. The first of her day-old ducklings appeared and, after stalling a minute at the nest's rim, launched itself from the ten-foot-high cavity. Spreading its stubby, but as yet ineffectual, wings, it plopped unhurt to the base of the Spanish-moss-draped oak. In quick succession, its siblings took the plunge, heeding the mother's calls and gathering around her. The hen seemed to count heads, and as soon as all of her ducklings—an even dozen in this case—were accounted for, the family headed into the marsh.

Ducklings are precocial; they need no catering in the nest. The morning after they hatch, downy wood duck young instinctively spring from tree cavities—or from nest boxes provided by helpful humans—and plummet to water or to the ground near a marsh, pond, or river. Although already adept at catching insects and nibbling aquatic greens, the ducklings will spend the next five or six weeks paddling in their mother's wake.—*Judy Rice*

May Events

Fort Lee Historical Park; PI PC

A diorama depicts the British invasion of New Jersey, November 20, 1776

May 1
Niles Eldredge, a curator in the Museum's Department of Invertebrates, will give a lecture based on his book *Dominion*, which traces three million years of human ecology. His talk begins at 7:00 P.M.

May 4
In conjunction with Asian/Pacific American Heritage Month, dance and craft presentations will be part of a day-long festival in the Hall of Ocean Life celebrating Asian and Pacific island cultures. Call (212) 769-5315 for details.

May 5
Juan Uson, of the National Radio Astronomy Observatory, will talk on "Discovery of the Largest Galaxy in the Cosmos and Other Curiosities in the Distant Universe." Part of the "Frontiers in Astrophysics" series, this lecture will begin at 7:30 P.M.

May 6
The state of the universe, portraits of cosmologists, and cosmological forecasting will be among the topics of a slide-illustrated talk by Timothy Ferris, author of the recently published *The Whole Shebang.* (For an excerpt from the book, see the March 1997 issue of *Natural History.*)

May 8
Chris McGowan will talk about the evolutionary relationships between dinosaurs and birds at 7:00 P.M. McGowan is a curator in the palaeobiology department of the Royal Ontario Museum and author of *Make Your Own Dinosaur Out of Chicken Bones.*

May 20 and 22
Drawing from their new book, *The Science of Jurassic Park,* Museum curator Rob DeSalle and physicist and science editor David Lindley will discuss dinosaurs and DNA research in two evening lectures beginning at 7:00 P.M.

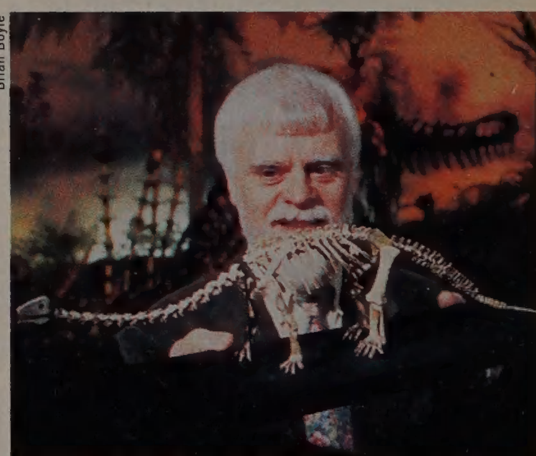
May 20 and 27
How the geology of the New York City area shaped the military activities of the Revolutionary War will be the subject of two Tuesday-evening talks at 7:00 P.M. by Sidney S. Horenstein, geologist and coordinator of the Museum's Environmental Programs.

May 21
A new exhibition in the Hall of Ocean Life, "Lost World: Dinosaurs Through Time," will feature clips, sets, and props from *Lost World* (the sequel to *Jurassic Park*), including the reconstruction of a 100-foot-long *Mamenchisaurus.*

May 22 and 29
National Park Service archeologist Robert S. Grumet will explore the complex ecological associations between the people and fauna of the Northwest Coast of North America in two Thursday-evening talks that begin at 7:00 P.M.

Throughout May
A variety of free programs celebrating Asian/Pacific American Heritage Month will be presented over the weekends of May 3–4, 17–18, and 24–25. For a schedule, call (212) 769-5315.

The Museum's IMAX Theater is featuring *Laserwarp,* a show about Earth's history, as well as the films *Stormchasers* and *Cosmic Voyages.*



Brian Boyle

Paleontologist Chris McGowan and his reconstruction of an Apatosaurus.

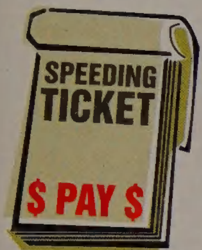
The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For tickets and information about events, call (212) 769-5200. Consult the Museum Web site (http://www.amnh.org) for additional information. For hours and admission fees, call (212) 769-5100.

TECHNOLOGY UPDATE

How to make your car invisible to radar and laser...*legally!*

Rocky Mountain Radar introduces a device guaranteed to make your car electronically "invisible" to speed traps—if you get a ticket while using the product, the manufacturer will pay your fine!

by Phil Jones



■ *The Phazer will "jam" both radar and laser guns, preventing police from measuring your speed.*

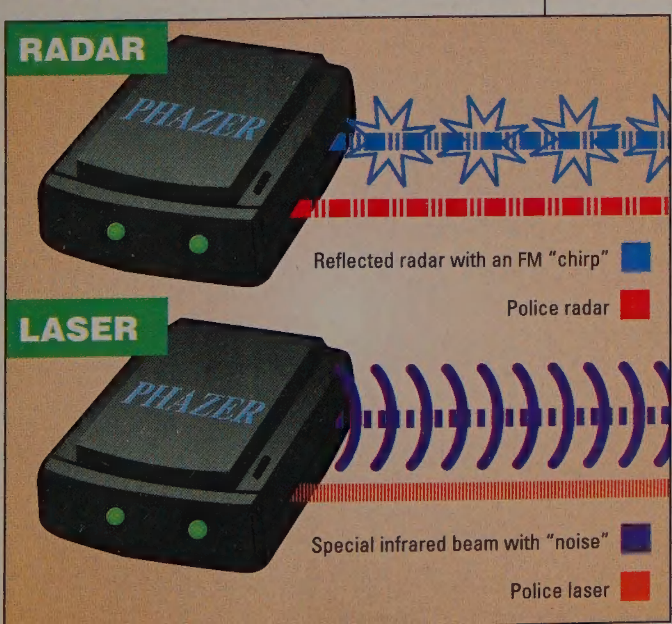
If your heart doesn't skip a beat when you drive past a speed trap—even if you aren't speeding—don't bother reading this. I can't tell you how many times that has happened to me. Driving down the interstate with my cruise control set at eight miles over the limit, I catch a glimpse of a police car parked on the side of the road. My heart skips a beat and for some reason I look at my speedometer. After I have passed the trap, my eyes stay glued to my rear view mirror, praying the police officer will pass me up for a "bigger fish."

It seems that as speed-detection technology has gotten more and more advanced, speeding tickets have become virtually unavoidable. And although devices exist that enable motorists to detect these speed traps, they are outlawed in many states... including mine.

The solution. Today, Rocky Mountain Radar offers drivers like me a perfect solution—the Phazer. Combining a passive radar scrambler with an active laser scrambler, the Phazer makes your automobile electronically "invisible" to police speed-detecting equipment.

The radar component works by mixing an X, K or Ka radar signal with an FM "chirp" and bouncing it back at the squad car by way of a waveguide antenna, effectively confusing the computer inside the radar gun. The laser component transmits an infrared beam that has the same effect on laser Lidar units.

Perfectly legal. Some radar devices have been outlawed because they *transmit* scrambling radar beams back to the waiting law enforcement vehicle. The Phazer, however, *reflects* a portion of the signal plus an added FM signal back to the police car. This, in effect, gives the waiting radar unit an electronic "lobotomy." Best of all, unless you are a resident of Minnesota, Oklahoma or Washington, D.C., using the Phazer is completely within your legal rights.



HOW TO MAKE YOUR CAR DISAPPEAR

Radar and laser scramblers are devices that foil speed traps by making vehicles electronically "invisible" to police radar. Radar scramblers mix a portion of the radar signal with background clutter and reflect it back to the squad car. This technique, pioneered by Rocky Mountain Radar, creates an unreadable signal that confuses the computer inside the radar gun.

The laser scrambler in the Phazer works in a similar manner. It transmits a special infrared beam with information designed to scramble the laser signal. The result? Readouts on police radar and laser guns remain blank. As far as the police officer is concerned, your vehicle is not even on the road.

■ *The Phazer makes your car invisible to police radar and lasers or the manufacturer will pay your speeding ticket!*

How it scrambles radar. Police radar takes five to 10 measurements of a vehicle's speed in about one second. The Phazer sends one signal that tells the radar the car is going 15 m.p.h. and another signal that the car is going 312 m.p.h. Because police radar can't verify the speed, it displays no speed at all. *To the radar gun, your car isn't even on the road.*

Works with laser, too! The Phazer also protects your vehicle from Lidar guns that use the change in distance over time to detect a vehicle's speed. The Phazer uses light-emitting diodes (LEDs) to fire invisible infrared pulses through the windshield. Laser guns interpret those pulses as a false indication of the car's distance, blocking measurement of your speed. *Again, it's as if your car isn't even on the road.*

Range up to three miles. The Phazer begins to scramble both radar and laser signals as far as three miles away from the speed trap. Its range of effectiveness extends to almost 100 feet away from the police car, at which point you should be able to make visual contact and reduce your speed accordingly.

Encourage responsible driving. While the Phazer *is* designed to help you (and me) avoid speed traps, it *is not* intended to condone excessive speeding. For that reason, within the first year, the manufacturer will pay tickets where the speed limit was not exceeded by more than 30%, or 15 miles per hour, whichever is less.

Double protection from speed traps. If the Phazer sounds good, but you prefer to be *notified* when you are in range of a police radar, the Phantom is for you. The Phantom combines the Phazer (including the Ticket Rebate Program) with a radar detector. It's legal in every state except Minnesota, Oklahoma, Virginia and Washington, D.C. Ask your representative for more details!

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Risk-free. Thanks to Rocky Mountain Radar, speed traps don't make my heart skip a beat anymore. Try the Phazer or the Phantom yourself. They're both backed by our risk-free trial and three-year manufacturer's warranty. If you're not satisfied, return them within 90 days for a full "No Questions Asked" refund.

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